LECTURE NOTES

ON FOREST ENGINEERING VOL II
ROADS, BRIDGES AND WATER SUPPLY

Compiled by
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VOLUME SECOND
(ROADS, BRIDGES AND WATER SUPPLY)

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By

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eventually. The path should be made passable for a pony, wherever possible, but high banks and deep cuttings should be avoided, the extra lengths being unimportant.

6. Forest roads, may also be classified as temporary, fair-weather and permanent roads depending on the duration for which the road is likely to be used.

7. The temporary roads are those which are made for extracting timber from near the felling site to the existing cart roads, and are required for just one or at the most two working seasons. Being purely extraction roads, they generally follow the valley and low ground. The alignment is taken round the spurs and other obstacles to avoid expensive cuttings and banks. Descents in the direction of loaded traffic are made steeper, and when it crosses small streams, the banks of the stream are cut down sloping to enable the carts to move down and up easily, and the bed is made possible by bullock carts (Fords).

8. Fair weather roads are those which are required for a number of years but are used only during the cold weather or working season, and are not open to traffic during the monsoon period. Fords a or Irish bridges form the main cross drainage works in such roads, culverts being hardly necessary. Gradients are kept low; deep cuts and high banks are avoided to keep down cost; two side drains are cut, one on either side to drain the roadway, the earth being thrown over the road way to provide a camber.

9. Permanent roads are those which are to be maintained in good order throughout the year, and hence their alighment and construction should be carried out with great care. Alternative routes should be considered making the road as straight and direct as possible, consistent with easy gradients and moderate cost. Shallow cuttings and embankments may be provided to avoid detours, but heavy rock cuts and long banks should be avoided. Culverts and bridges may be provided where absolutely necessary, irish bridges and causeways being prefered in the forest roads. The road should be raised well above the general ground level to keep it dry, and the side drains provided. In heavy rainfall areas, the road will need metalling to prevent heavy erosion.

3. Section of Forest Road:

1. Fig. 1 shows the common forms of cross-section adopted for the forest cart-roads. To prevent the rain water from stagnating on the road surface resulting in rendering the surface soft, the centre of the road is raised above its edges. This raising of the centre of the roadway above its edges is known as camber.

2. Two longitudinal or side drains or ditches are cut along the sides of the road to carry off the rainwater to a natural outfall. Two types of longitudinal drains are shown, the trapezoidal and the V-drains. The dimensions of these drains will depend upon the rainfall in the locality, the normal dimensions being as shown in the figures.

The V-drains are generally preferred, since there is less danger of the wheels getting stuck in the ditches.

3. Hill roads:- There is a lot of controversy regarding the transverse profile to be given to hill roads. Many engineers

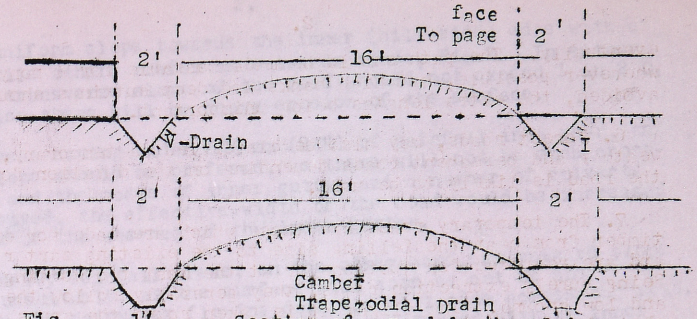
face
To page
2'
16'
2'
V-Drain
I
2'
16'
2'
Camber
Trapezodial Drain
1'

Fig. Section of a road in the plains

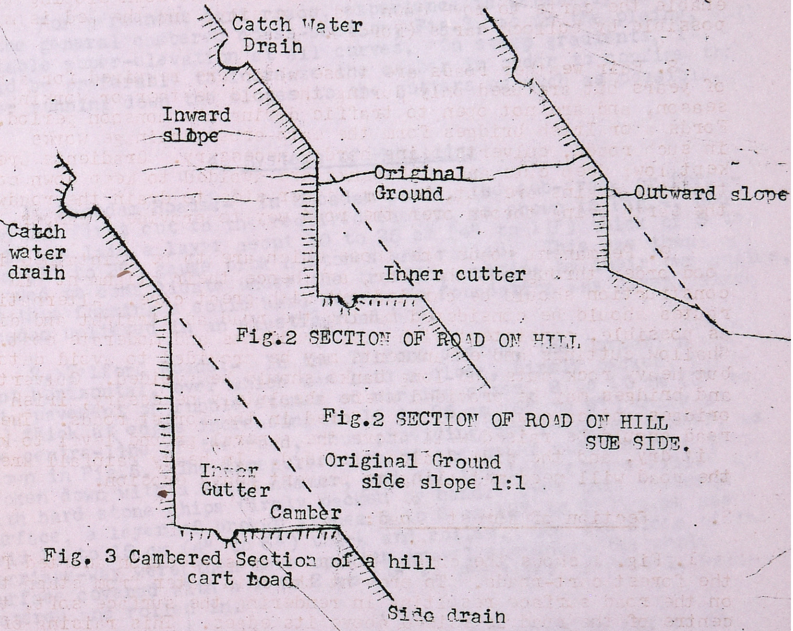
Catch Water Drain
Inward slope
Original Ground
Outward slope
Inner cutter
Catch water drain
Inner Gutter
Original Ground side slope 1:1
Camber
Side drain

Fig.2 SECTION OF ROAD ON HILL

Fig.2 SECTION OF ROAD ON HILL SUE SIDE.

Fig. 3 Cambered Section of a hill cart road

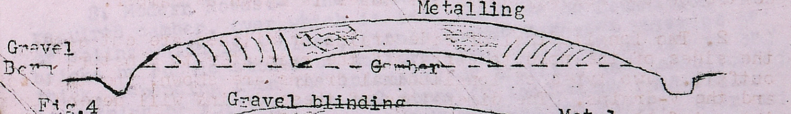
Metalling
Gravel Berm
Camber
Gravel blinding

Fig.4 MACADAM ROAD

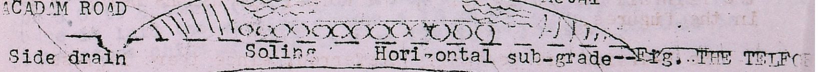
Metal
Side drain
Soling
Horizontal sub-grade

Fig. THE TELFOR

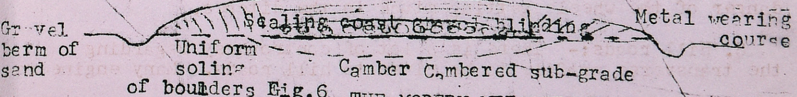
Sealing coat gravel blinding
Metal wearing course
Gravel berm of sand
Uniform soling of boulders
Camber
Cambered sub-grade

Fig.6 THE MODERN METALLED ROAD

favour a uniform slope towards the inner (hill-side) edge with a gutter, while others prefer an outwards slope, Fig.2. In either case, the transverse slope of the road should not exceed 1 in 20, as otherwise there will be heavy erosion of the surface.

In areas having under 500 mm (20") of rainfall in a year, an outward slope should be prefered, as there will not be much cross-drainage, and the costs of inner gutter and a number of culverts would be saved, the effective width of the road would be increased on account of the absence of the inner gutter.

In heavy rainfall areas, on the other hand, an outward slope would be unsuitable, as the surface will soon be cut up and damaged by the rainwater flowing down the hill side across the road. In such a case, an inward slope would be preferred with an inner gutter to intercept the hill-side drainage.

For permanent cart roads, experience is generally in favour of the general cambered corss-section, Fig.3, as in the plains, with suitable super-elevation at all curves. On steep gradients, it would be preferable to increase the camber in order to confine the water running down the slopes to the gutters as much as possible.

4. Systems of Metalling

1. Macadam Roads:- In Macadam roads, the sub-grade or formation was first cut to the required camber, as shown in Fig.4, and on it was laid a layer about 10 to 25 cm (4" to 10") thick of 5 to 8 cm (2" to 3") gauge broken stones and rolled. This was then allowed to consolidate under the traffic, uniting by their own angles, and thus forming a solid hard mass. No foundation was given, since Macadam believed in an elastic road bed.

2. Telford Roads:- In the Telford system, the formation was kept horizontal, over which was laid a close, firmly packed, hand-set, pavement of rubble stones of varying sizes, 8 to 10 cm (3" to 4") thick at edges increasing to 15 to 25 cm (6" to 9") thick at the centre-line of the road, thus providing the required camber, as shown in Fig.5. The irregularities of the upper surface were then broken down with a light hammer, and all the interstices filled up with hard stone chips firmly packed by hand. Over this cambered surface, a layer of broken stones 5 to 6 cm (2" to 2") gauge was laid 10 to 15 cm (4" to 6") thick and rolled. The two sides of the carriage-way were then made up with gravel shoulders the whole surface covered with a 1 to 2 cm (½" to ¾") layer of gravel, well-watered and rolled in.

3. Modern Roads:- The formation or Sub-grade is cut to the required camber, over which is laid the base or foundation course or soling which is a close, firmly packed hand-set payement of bricks or rubble stones of uniform size, 10 to 20 cm (4" to 8") thick, depending upon the intensity of traffic, and consolidated by ramming or rolling with a 2 tonne (2 ton) stone road-roller or a 6 to 8 tonne (6 to 8 ton) steam road-roller Fig.6. Over this base is laid the wearing course a 10 cm (4") layer of hard material like stone chips about 5 to 8 cm (2" to 3") size. On this is

spread a 1 to 2 cm ($\frac{1}{2}$" to $\frac{3}{4}$") blinding courses of murum or clean gravel, well watered to form slush and rolled to blind all the sharp corners and provide a smooth running surface. The whole surface is then covered with the a thin 5 mm ($\frac{1}{4}$") layer of sand or fine bajri, and rolled in to act as a sealing coat both to prevent mud sticking to the roller and to prevent rain water sinking into the gravel and forming slush again.

5. Gradients.

1. Gradient is the longtitudinal slope of the centre-line of the roadway. It is generally expressed in terms of the horizontal distance in which the road rises or falls by one unit. Thus a gradients of 1 in 20 means a rise or fall of one metre (foot) in a horizontal distance of 20 metres (feet).

2. The gradient may be expressed as the degree of elevation or depression of the road surface with reference to the horizontal plane. A slope of 1° equals a rise of 1 m (foot) in 57.3 m (feet) horizontal, so that a gradient of 2° may be taken as 1 in 28.6 and that of 3° as 1 in 19.1, etc.

3. In American practice, the gradient is expressed as a percentage of the horizontal distance. Thus a gradient of 1 in 20 is expressed as a 5% grade.

4. Importance of gradient:- A truck which can haul a loan of 3 tonne (tons) on the level stretch of an earth-road, can haul on the same gear, only 2 tonne (tons) up a 1 in 20 gradient, and only 1 tonne (ton) up a 1 in 10 gradient. On the smooth hard surface of a metalled road, the effect of the gradient is even greater, only half the load being hauled up a 1 in 20 gradient compared with a load on the level surface.

5. The disadvantages of a steep gradient are:-

(1) Loss of power-cartmen adapt their load to suit the steepest gradient, on the road thus wasting power over long stretches of easy gradients.
(2) Scouring action of water running down the road.
(3) Destructive influence of brakes and skidding of wheels on down gradients.
(4) Greater wear and tear of road by animal feet and fatigue to animals.

6. Absolute Maximum Gradient is the steepest slope which animals drawing a load can traverse for a short distance, by exerting double the energy required to haul the same load on level ground.

7. Ruling Gradient is the steepest gradient fixed for a particular stretch of road depending upon the nature of the terrain in the locality.

8. Ruling gradient may be exceeded for short lengths of say, half km (mile) in very difficult terrain, only when absolutely unavoidable, but the maximum gradient shall not be exceeded in any circumstances.

A Minimum gradient of 1 in 100 should be provided, particularly in long cuttings, to facilititate proper drainage.

9. Average gradient is the ratio of the sum of all rises and falls in the road to the total horizontal distance travelled. This lies between the minimum and ruling gradients on the road, and the earthwork will be a minimum when the gradients approach the average gradient.

10. The following table gives the general dimensions recommended for an ordinary single lane forest road:-

Class of road	Width	Camber	Gradient	
			Maximum	Ruling
Main Cart road	3.5 m (12')	1/20 to 25	1 in 15	1 in 20
Feeder Cart road	3 m (10')	1/15 to 1/20	1 in 10	1 in 15
Bridle Path	2 to 2.5 m (6 to 8')	--	1 in 5	1 in 8
Inspection Path	0.6 to 1m (2 to 4')		1 in 2	1 in 5

SECTION 2. FOREST ROAD ALIGNMENT

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6. Reconnaissance

1. The Object of reconnaissance is to produce a report and a rough map setting forth all reasonable obligatory points, and all reasonable methods of connecting them, from which one or more trial lines can be selected for a more detailed preliminary survey, A thorough reconnaissance will save a lot of unnecessary cost both in construction and in subsequent maintenance of roads.

2. The Main features to be observed during reconnaissance for a road are:-

(1) The natural features of the country.
(2) Gradients anticipated, for fixing a ruling gradient.
(3) Obstacles to be negotiated, such as a ridge a steep precipice, or a valley, etc.
(4) Existing paths, culverts, etc., if any, which can be utilised.
(5) Rough elevations of hills, saddles, passes, valleys and other important places to be touched.
(6) Positions of wells, water-holes, perennial streams, etc.
(7) Requirements of local traffic, market places, etc.
(8) Availability of materials of construction and labour.
(9) Advantageous sites of bridges and culverts for crossing streams as regards good foundations.
(10) Details of any earth slides, marshy places, etc. which are to be avoided.

3. If a contoured map of the area is available the possible routes connecting the terminal points on the ruling gradients can be marked on it, starting from the highest contour to be touched and stepping off the horizontal equivalents between successive contours. The most smooth running and the best of these lines are selected for further examination by walking over the whole lengths of these routes on ground, paying special attention to broken ground, stream-crossing, etc.

4. When a contoured map is not available, a more detailed examination of the country is called for, before fixing a rough alignment. An Abney level may be used to control the gradients and a hand compass will assist in fixing directions.

7. Alignment of a Road in the Plains.

1. Main roads should be located centrally in the area with necessary feeder roads. The chief considerations here would be:-

(1) To avoid unnecessary crossings of streams and natural drainage channels
(2) To keep to high ground wherever possible to keep the road dry.
(3) To avoid swamps and low-lying areas, and heavy rock-cuts.

2. The monotony of a very long and straight road should be broken by introducing reverse curfes, and planting trees or digging wells, to hide the continuation of the road.

3. A small deviation upto 10% of the length of the road will increases its length by hardly 2% and the road can, therefore, be profitably diverted to touch any stone quary, a village, a rest house, or a railway station, which will help the growth of the locality.

4. To negotiate an isolated hill or block of hills intervening between the terminal stations, a detour is permissible, if the increase in length does not exceed upto 20 times the unnecessary rise saved by it.

5. Existing roads in the area should be utilized, as far as possible.

6. Private land should be avoided to effect economy in acquisition of land.

7. Small streams may be bridged as they are met, but for bigger streams, deviations may be provided to connect good bridge sites.

8. Alignment of a Hill Road

1. An Extraction Road should follow the valleys, and should be as near as possible to the lower boundary of the working areas, so that timber can be dragged downward to the road for transport. A main Communication Road, on the other hand, should, wherever possible, follow the ridges to keep them dry.

2. The main points to be kept in view are:-

(1) Start from higher obligatory points to the lower obligatory points on either side.

2(2) Unnecessary ascents and descents should be avoided. Even foot of elevation gained must be maintained.

(3) Take the road on the sunny side of the valley or the side exposed to dry winds, since it will keep the road dry.

(4) Try to keep the line within the ruling gradient, unless unavoidable. Start with a gradient slightly flatter than ruling gradient, easing it at all re-entrants, culverts and bridges, curves, etc.

(5) Approaches to a bridge should be carefully selected so that

(a) they are straight for about 50 metres (yards) on either side. If a curve is unavoidable, proper widening, super-elevation, and sighting distances should be provided.

(b) they are not in deep cuttings, to improve visibility and avoid drainage problems.
(c) they are above the high flood level.
(d) their gradients are eased off, if it is impossible to have a level stretch of road over the bridge.

(6) Avoid heavy rock-cuts and places liable to land-slips, and also deep cuttings and high embankments by detours to economics.

(7) Avoid hairpin curves and zig-zags wherever possible, as they are difficult to construct and maintain and dangerous to negotiate. If unavoidable, a hair-pin curve may be laid out as shown in Fig. 7.

(8) In long continuously rising roads, provide halting and watering places at intervals.

(9) Take the road on that side of the hill where the strata are dipping into the hill, Fig. 8 and avoid the side where the strata are dipping towa-rds the foot of the hill, Fig. 9.

(10) Wooded slopes of valleys are preferable to bare slopes, as they make the roads picturesque and also useful.

(11) Avoid long stretches of dead-level roads as they hold up surface water and are difficult to drain.

(12) While negotiating a deep ravine on ruling gradient, provide a reverse gradient (a downward gradient from both sides of the valley towards the bridge), to provide for future improvements of the crossings as at I,II,III Fig.10.

9. Preliminary Survey

1. The best route selected will then be surveyed in detail. The proposed line is first pegged out in series of straights, grading carefully with a Ceylon ghat tracer or an ordinary Abney level, easing the gradients wherever necessary. This will be followed by a prismatic compass survey, taking the lengths and bearings of all the straights, removing the original pegs and putting in fresh "numeral pegs" at uniform intervals, usually 20m (1 chain) and also at corner points. The level of each peg is then found by using a level, and cross slopes at each peg are measured with an Abney level at right angles to the line.

2. Notes must be made of the nature of the soil, rock, jungle-clearance, drainage lines, sites for irish bridges, culverts, retaining walls, etc. and positions where stone-revetments are required, etc.

3. In short lengths of forest roads the operation of levelling may be omitted, the levels of the pegs being calculated from the ghat tracer readings and the lengths of sights. Also the area of cross-section at each peg can be found by using a Slope

template (see page 21), and the tedious work of taking cross slopes by abney level and plotting sections of the road for finding areas of earthwork at each peg avoided.

10. Paper location.

1. The object is to arrive at the best combination of straight curves and gradients which will form a centre-line for the proposed road, requiring a minimum of earthwork. A plan is drawn from the data obtained by the prismatic compass bearings and lengths, Fig.11, the scales generally used for the plan being 1/1000, 1/2000, 1/5000, etc. (1"=100', 200', 300').

2. Then a Longitudinal section is drawn along this line to the same horizontal scale as that of the plan, while the vertical scale is taken 10 to 20 times the horizontal scale, to exaggerate the gradients. On this longitudinal section, the proposed road is graded i.e., a combination of gradients selected, all of which are flatter than the ruling gradient, if possible, but which follow the ground line as closely as possible, Fig.II.

This is th Formation level of the road and will show at a glance which lengths of the road are in cutting and which in filling. The ground line is generally drawn in black ink, while the formation line is in red; cuttings are coloured red, while embankments are coloured blue.

3. Cross-section at each peg is then drawn using these formation levels and the cross-slopes obtained from abney level readings, the depths of cutting and heights of filling being taken from the longitudinal section. If area of earthwork is found excessive at any peg, the plan line may be shifted to the right or left, to reduce the earthwork at these sections. The amount of this shift should be shown in plan, and the resulting changed ground level (as calculated from the cross-slope and distance of shift) shown in the loggtitudinal section. Care should be taken to see that irregular shifts of the centre line does not make road crooked.

4. The positions of the pegs for the finally decided location in relation to those already driven in the ground should be neatly recorded in the field book for setting out on ground.

11. Demarcation of Alignment

1. It usually takes a year or more after the alignment is pegged, before estimates are approved and work started. As soon as the alignment is approved, therefore, the temporary pegs must be replaced by permanent ones. Two kinds of pegs are generally used, the numeral and the grade pegs.

2. Numeral pegs should be of durable wood, about 5 cm (2") in diameter and 50 cm (20") long pointed and driven into the ground at least 25 cm (10") deep with a wooden mallet, Fig. 12.

These are serially numbered, so that the peg number will indicate the distance from the commencement of the alignment. Thus peg number 27 should mean 27 chains from commencement, while 27--A may be a peg between 27 and 28 chains.

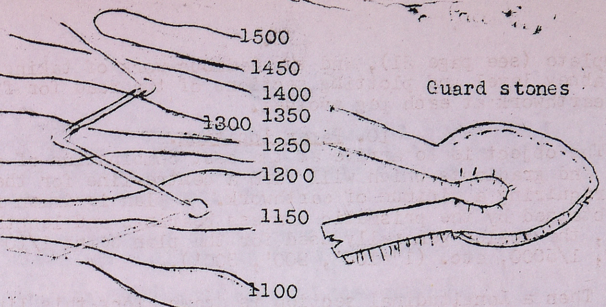

1500
1450
1400
1350
1300
1250
1200
1150
1100
Guard stones

Fig.7 ZIG-ZAGS AND HAIR-PIN CURVES

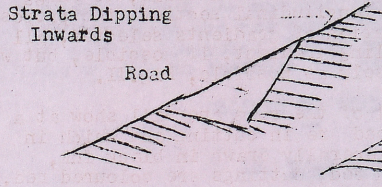

Strata Dipping Inwards
Road

Fig: 8 ROAD SAFE

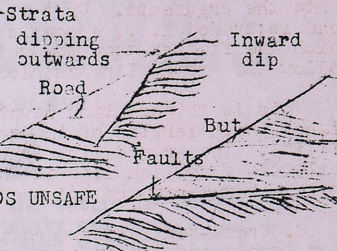

Strata dipping outwards
Inward dip
Road
But
Faults

Fig.9 ROADS UNSAFE

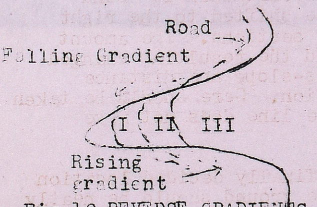

Road
Falling Gradient
I
II
III
Rising gradient

Fig.10 REVERSE GRADIENTS

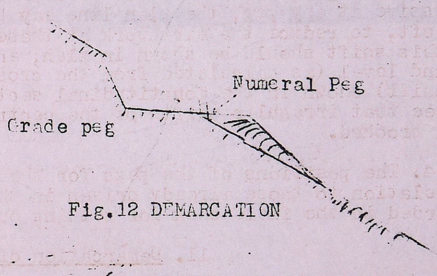
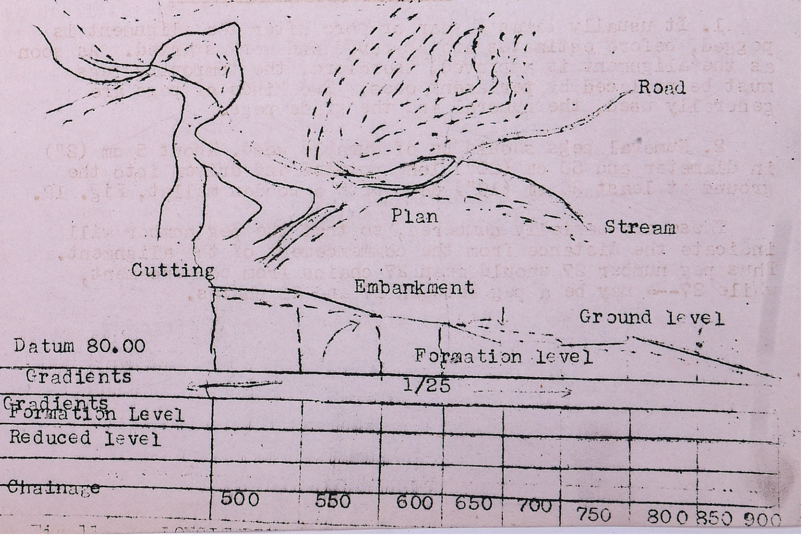

Numeral Peg
Grade peg

Fig.12 DEMARCATION


Road
Plan
Stream
Cutting
Embankment
Ground level
Datum 80.00
Formation level
Gradients
1/25
Gradients
Formation Level
Reduced level
Chainage
500
550
600
650
700
750
800
850
900

3. Grade pegs:- By the side of the numeral pegs, small grade pegs 15 to 25 cm (6" to 9") long and 2 to 3 cm (1") dia are driven into the ground, so that their tops are just at the formation levels of the road. Fig.12.

Where deep cuttings or fillings are to be done, big pegs are driven and depths of cuttings or filling written on it.

4. 30 cm trace:- Then a 30 cm (1') line must be cleared by cutting down all growth under 15 cms (6") girth, and cut to the proposed formation level for the whole length of the road. Big trees or bamboo clumps are not cut, but gone round also deep cuttings and fillings are not done, but the levels should be resumed as soon as possible. Trees on either side are blazed on the side of line to indicate the direction at a later date.

SECTION 3. ROAD DESIGN

12. Road width.

1. The width of road depends upon the nature and intensity of traffic expected on it, the availability and cost of land, and on the financial resources. The normal widths of roadway generally provided are as follows:-

Type of road	Single lane		Double lane	
	Standard	Recommended	Standard	Recommended
Cart roads	3m(10')	3.5m (12'	6m(20')	6.5m(22')
Bridle paths	2m(6')	2.5m (8')	3m(10')	3.5m(12'

2. Land:-- The above table gives the actual width of roadway, but the width of land to be acquired for making a road should provide for the road-way proper, the two shoulders on either side, side slopes of cuttings and embankments drainage arrangements like longitudinal side drains and any catch-water drains, side-widths for stacking materials for future maintenance, land for any borrow-pits or spoil banks, and also provision for possible widening of the road at a future date.

Where land is not particularly costly, the width of land to be acquired is 20 m (66 ft.) and it may be profitably increased to 25 m (82½ ft.) in cheap land.

In the case of hill roads, the minimum width required for locating the entire road, including the inner gutter and catch-water drains should be acquired.

3. In the case of Forest Roads, every attempt should be made to align the road entirely on Government land, to avoid the expense and litigation of acquiring private land.

13. The Shoulders

1. Shoulder is the portion of the road between the edge of the roadway and the side drain, Fig.6. A minimum width of 60 to 100 cm (2 to 3 ft.) of shoulder should be provided on either side of the roadway. It should be dressed in continuation of the camber of the roadway, and never allowed to become higher than the roadway, as the roadway would then become a drain.

2. Its main functions are to support the sides of the roadway, to prevent the metal from spreading under the load, to provide extra width for crossing and precedence of vehicles and to provide space on which to divert traffic during repairs and renewals of the roadway.

3. The shoulder should always be kept clean and tidy, free from shrub and jungle growth, and no excavation should be permitted in the shoulders.

14. Camber

1. Camber is the transverse barelling of the road provided by raising the centre of the road above its edges in order to quickly drain away the rainwater falling on the road surface, Fig.1.

2. It is generally expressed in terms of the transverse slope of the road. Thus a camber of 1/20 means that the centre of the road is raised above its edges by an amount equal to one-twentieth of half the width of the road; e.g. if the camber on a 3m (10 feet) wide road is $\frac{1}{20}$, the centre will be raised by $\frac{1}{20}$ ($\frac{1}{2}$x3) = 0.075 m or 7.5 cm ($\frac{1}{20}$ ($\frac{1}{2}$x10') = $\frac{1}{4}$ foot or 3").

3. The amount of camber to be given depends upon the nature of surface of the road. The following table gives the cambers generally adopted.

Earth road..	6 to 4% ($\frac{1}{20}$ to $\frac{1}{25}$)
Metalled roads	4 to 3% ($\frac{1}{25}$ to $\frac{1}{30}$)
Corduroy or Plank Roads ..	5 % ($\frac{1}{20}$)
Black-topped roads	3 to 2.5% ($\frac{1}{30}$ to $\frac{1}{40}$)
Cement Concrete roads ..	2% ($\frac{1}{50}$)

A greater transverse slope than the above would tend to tender the road slippery.

15. Section on Side-long ground

1. The road will be most stable when it is entirely cut out of the hill-side but this will be very expensive. For economy, therefore, generally two thirds of the formation width (including the shoulders and inner gutter) may be made by cutting out from the hill-side, and the earth so obtained utilized to form the embankment on the down hill side. When the

cutting is to be in rocky area, it may be more economical to build up half or even more of the width, as it may be more economical to construct the necessary retaining walls than to blast the entire road-width from the rock bed.

2. When the entire road is thus mostly in cutting, the alignment pegs should follow the edge of cutting and not the centre line road.

3. On steep hill slopes, retaining walls become necessary, Fig.13, though on gentle slopes, the ground may be cut in series of steps drop, towards the hill side, before filling in the soil to make a stable embankment.

4. When the hill-side is normally stable, but becomes liable to slips due to changes in weather conditions it may be supported by breast walls.

16. Gradients

1. The recommended gradients shown in Art 5 should be maintained as far as possible.

2. Efforts must be made to keep the gradient as gentle as possible, and not to exceed the ruling gradient anywhere. But in very steep hill roads, where unavoidable, the gradient may be increased up to the maximym gradient, but only for very short lengths not exceeding a 1 km (½ of a mile) at a stretch in any case. Attempts must be made to provide easy gradients or level stretches on either side of such steep grades.

3. In long continuously rising roads, sufficient halting and watering places should be provided at suitable intervals. Also at least two (four) passing places about 25 m (80) feet long, should be provided in each kilometre (mile) of single-lane roads; where it should be widened to double-lane width.

4. To ensure proper drainage, a road in full cutting should be given a minimum gradient of 1 in 100 throughout, or a falling gradient from the centre of the cutting length towards each end.

5. A change of grade should never be provided on an embankment since it cannot be maintained, and curves on embankments should be avoided as they will require wider banks.

17. Earthwork

1. Much unnecessary labour and expense in building a road can be saved by a careful treatment of earthwork, while grading the road in the longitudinal section. The cuttings and embankments along the centre-line of the road should be arranged in such a way that the earth obtained from a cutting can be utilized in forming an embankment nearby. Otherwise borrow pits will have to be excavated for earth, which will mean more expense.

But if the cuttings and embankments are situated far apart, it may be cheaper to form the bank with earth obtained from borrow pits by its side than by transporting the earth from the cutting, in which case borrow pits should be provided for.

2. The cross-sections of hill-side roads should be so arranged that earth obtained from cutting on the up-hill side is utilized in forming the embankment on the down-hill side, as far as possible. To ensure this, it is better to have 60% of the formation width in cutting and the remaining 40% in embankment except in rocky areas.

In narrow roads like bridle paths, however, the entire road may be made in cutting since that would be the most stable condition, and the earth so obtained thrown on the down hill side to obtain an extra width for the road.

In rocky areas, the amount of blasting should be reduced, and the road should be made more in banking (with any retaining walls that may become necessary) to minimise cost.

3. Side-slopes:-- The side-slopes of cuttings and banks will depend upon the natural angle of repose of the soils. Cuttings will be able to stand at steeper slopes than banked soils, since the soil in a cutting has been compacted for a long time. It is best to make trial pits at intervals along the line to find the nature of the soil and its natural angle of repose.

For cuttings, a side-slope of 1 vertical to 1 horizontal (1:1) is generally adopted for all ordinary soils, Fig.11. But steeper cutting slopes of 2:1, 3:1 or 4:1 may also be adopted for firm gravelly soils. The rock-cuts may be given vertical faces or even a over-hand, but flatter slopes of 1:1½ (1 vertical to 1½ horizontal) may have to be adopted in soft soils like heavy clay or black cotton soils.

For embankments, on the other hand, a side-slope of 1:1½ (1 vertical to 1½ horizontal) is generally adopted. Slopes steeper than this will need support by either revetting or by retaining wall. Heavy clays should not be used for making embankments, but if unavoidable, flatter side-slopes 1:2 to 1:3.

18. Drainage of Roads in the Plains

1. The drainage System of a road comprises of drainage of the road surface, of the foundation, of sub-soil and of ground in the vicinity of the road. A road should be kept well drained, as otherwise it will become soft and disintegrate under the load of traffic.

2. Drainage of Surface:-- Rainwater falling on the road proper is made to run off into the side drains by providing the necessary camber to the road, as explained in Art 14.

3. Drainage of Foundation:-- In the metalled roads, the voids between the large soling stones permit any rain water soaking through the surface to find its way into the sub-soil, from which it is drained into the side ditches.

The gaps between timbers in the corduroy or plank roads are enough to ensure proper drainage.

4. Drainage of Sub-Soil :-- A badly drained sub-soil will cause irregular settlements and subsequent breaking up of the road surface.

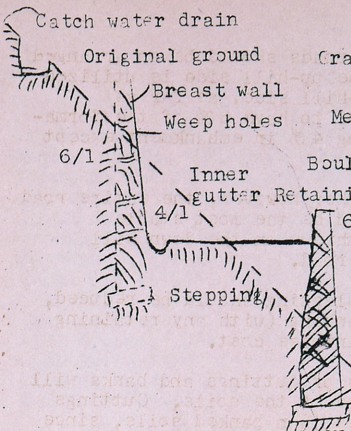

Catch water drain
Original ground
Breast wall
Weep holes
6/1
Inner
gutter
4/1
Retaining wall
6/1
Parapet
Stepping

Fig.13 SECTION OF ROAD ON SIDE-LONG GROUND

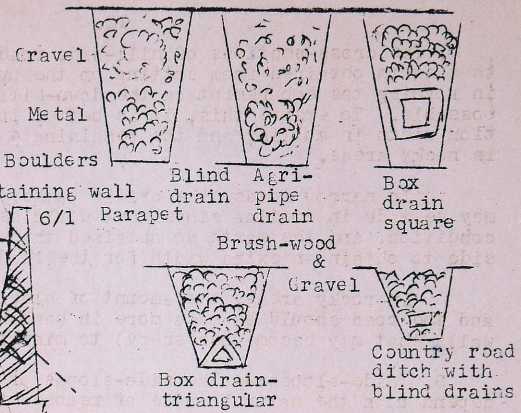

Gravel
Metal
Boulders
Blind
drain
Agri-
pipe
drain
Box
drain
square
Brush-wood
&
Gravel
Box drain-
triangular
Country road
ditch with
blind drains

Fig. 15 COVERED DRAINS

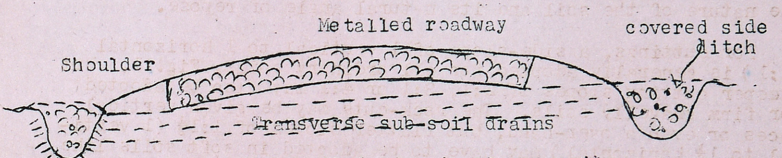

Metalled roadway
Shoulder
covered side
ditch
Transverse sub-soil drains

Fig. 14: Sub-soil drains in clavey soils

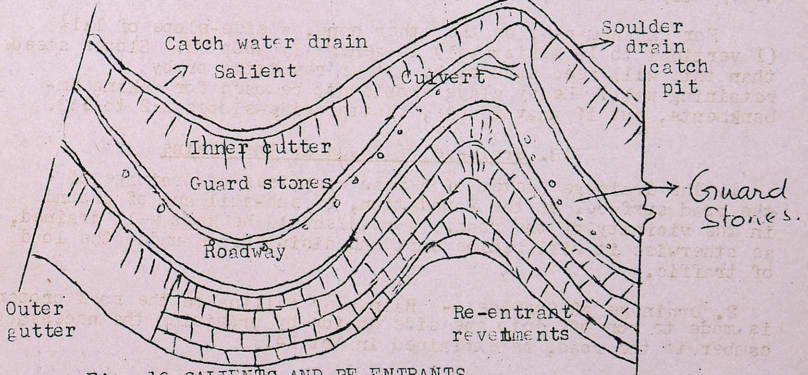

Catch water drain
Salient
Culvert
Soulder
drain
catch
pit
Inner gutter
Guard stones
Guard
Stones.
Roadway
Outer
gutter
Re-entrant
revetments

Fig. 16 SALIENTS AND RE-ENTRANTS

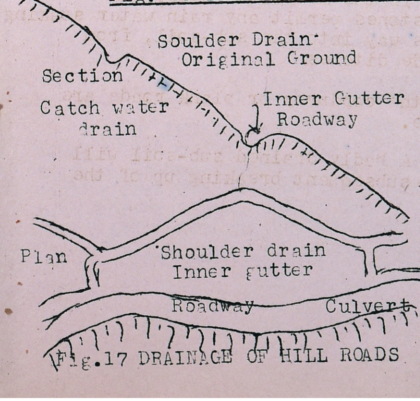

Soulder Drain
Original Ground
Section
Catch water
drain
Inner Gutter
Roadway
Plan
Shoulder drain
Inner gutter
Roadway
Culvert

Fig.17 DRAINAGE OF HILL ROADS

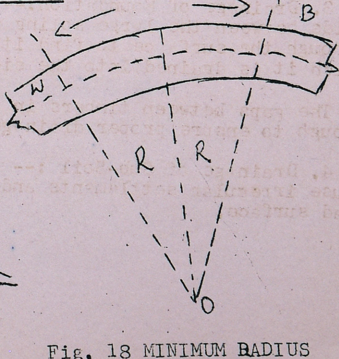


Fig. 18 MINIMUM RADIUS OF CURVES

The sub-soils may be classified as Permeable and impermeable soils, and salid rock. Permeable soils, like gravel and sand, do not present any difficulty since water will find its way through them into the side drains. In the impermeable clays and hard rocky beds, sub-soil drains will have to be provided to drain the water into the side drains as in Fig. 14. In heavy clays narrow but deep transverse drains are cut 40 to 50 cm (15 to 18") below the formation level and given a fall of 1 in 50, and then filled with shingles, gravel brick-bats, or sand to lead the water soaking through the surface into the side drains. The spacing of these sub-soil drains will depend upon the nature of soil, being 10 to 20 m (33 to 66 feet) apart in very heavy black cotton soils, and about 30 to 60 m (100 to 200 feet) apart in pure clayey formations.

As a rule, solid rock formations doe not give any trouble as regards drainage, but a 10 cm (4") cushioning layer of sand or murum should be provided on a bed of hard rock to prevent the road-metal from being pounded up before it has had time to bind together.

Every road should be a watershed and never a water-course, and therefore, the tendency to dig up the formation for laying the soling stones should be strictly guarded against. The formation should be compacted first, and then the foundation and wearing course biilt up bringing up the shoulders simultaneously.

5. Drainage of ground in the vicinity:-- Rainwater falling on either side of the road will be drained by the side ditches. These should normally be wide and shallow, since the earth-sides of deep narrow drains frequently collapse and block the drain, causing the water to rush on to the road surface and damage it.

A good section for the side-drawins in permeable soils would be 60 to 100 cm (2 to 3 feet) top width, narrowing to 50 cm (1'6") at the bottom, with a depth of about 30 cm (1 foot) as shown in Fig. 1. The bottom of the drain should be kept about 25 cm (1 foot) below the fomation level, in order to intercept the water percolating through the sub-grade. A bed-slope of 1 in 100 should be given to these drains so that water may easily flow down them.

In impermeable soils, where sub-soil drains are provided the side-drains will have to be deep trenches, which become dangerous to the traffic and the sides of the ditchesbecome liable to collapse under the pressure of traffic. In such cases, it is usual to provide covered side-ditches, some forms of which are shown in Fig. 15.

19. Drainage of Hill Roads.

1. The Inner gutter:-- The gutter may be of the normal size, about 60 cm (2') side at top and half as deep to carry the surface drainage between the centre line of the road and the catch-water drain. In rock cutting or hard soils the drain need not be lined, but in soft soils it may be necessary to revet its sides and bottom with bricks or stones or even concrete.

2. Where abrupt salients (the curve of road round a spur)

occur on a steep grade, the inner edge of the gutter should be protected by fixing guard posts along the edge; otherwise, the side of the gutter may collapse under the load of traffic and block the drain, causing the water to rush on to the road resulting in erosion.

3. The inner gutter should be let into the nearest natural water-course and where such are not available, it will be necessary to pass the water at intervals by means of cross-drains such as Irish bridges or Culverts under the road. These cross-drains should be taken at right anglesto the road and their floors must be given the same slope as that of the water course; the floor of the culvert may have to be paved if there is any danger of scour, and, in such cases, a stone or brick apron has to be provided on the down-hill side to carry the discharge safely down the lower slope Fig.16.

4. At the entrances of all culverts, a catch pit (Fig.16) must be provided to collect slit and rubbish in order to prevent the choking of the culvert. The bottom of the catch-pit should be at least 30 cm (1 foot)) below the floor of the cross-drain and in soft soils the sides and bottom may be lined with stone or brick work.

5. The outer gutter:-- If the drainage of the up-hill side of the road is properly dealt with, the outer gutter may be just a small drain, about 20 cm (8")) wide 10 cm (4") .deep, to carry the rain-water from the outer half of the road. The water should be let out through the parapet or earth-protection mound by drainage hole or channels (sometimes referred to as shoulder drains) at frequent intervals. It is advisable to place the guard-post right in the outer gutter immediately below a drainage hole, so that the water is deflected into the latter.

6. Catch water drains:-- These drains provided about 5 to 10 m (15 to 20') abouve the edge of cutting on the up-hill side of the road to intercept the rain water running down the hill-slopes. These would start from above the water-sheds of salient on the road (at a spur) and dip down to there-entrants (at valleys) on either side, thus forming an inverted V(A) in plan as shown in Fig.17. They may be made about 1.2 m (4') wide at top, 60 cm (2 feet) wide at bottom, and about 60 cm (2') deep normally, and the size will depend upon the area drained and the rain-fall.

7. On a long hill-side, where these catch water drains tend to become too long and cannot be led into a natural water-course, they are connected to the inner gutter by cross or shoulder drains-- Fig.17 and an irish bridge or culvert provided to passthe water to the down-hill side of the road. On steep hill sides it may be necessary to revert these shoulder drains and on steep side-slopes of the cutting it may even be necessary to embed pipes to act as shoulder drains.

20. Road Curves

1. The curves on roads are generally circular curves and no transition curves are provided since speeds of road traffic in India are not so high. But very sharp curves should be avoided as far as possible, except on hill roads, where the road has to follow the hill-folds.

2. A minimum radius of 50m (150') along the centre-line should be attempted for roads in flat ground, and a minimum radius of 20m (60') on hill roads, which may be reduced to 1[illegible] m (35') in very difficult terrain.

3. Hairpin curves are very sharp curves on a hill-side changing direction by 180° where there is no possibility of taking the road round a spur. Hairpin bends and zig zags (a series of hair-pin bends), should be avoided as far as possible, since they are both difficult to construct and maintain and dangerous to the traffic. Where absolutely necessary, they should be provided on gentler hill slopes, say less than 30° slopes, partly by cutting into the hill-side and partly by raising the outside with banking supported by a retaining wall. A simple form of hair-pin curve is shown Fig.7, which is suitable for adoption on Forest roads.

4. The minimum radius R metres (ft.) of a circular curve along the centre line of the roadway required to permit transport of a log of length/metres (ft.) may be found from the formula (see Fig.18)--

$$R == \frac{l^2 + w^2}{4\,w}$$

where w == width of road in metres (feet).

+Thus the minimum radius required for transporting a 15 m (40 feet) log on a 3m (12') wide cart road would be

$$\frac{15^2 + 3^2}{4x3} = 19.5 \text{ or } 20m \; (\frac{40^2 + 12^2}{4+12} = 34 \text{ feet})$$

21. Clear Vision

1. In hill roads, where the road is winding along the hill-folds, the vision is obstructed in salients by the spur at re-entrants by heavy growth of trees. A minimum Sighting Distance of Clear Vision or 50 metres (50 yards) should be provided for the drivers of fast moving vehicles to avoid collisions.

2. This may be provided at re-entrants by cutting down the jungle growth, and at salients by cutting back the spurs at a height of 50cm (1½') above the road level as shown in Fig. 19.

3. When two steep opposite gradients meet in a ridge a level portion or a suitable vertical parabolic curve should be provided between them to have the minimum sighting distance.

22. Super-elevation

Super-elevation is the cross-banking of the road surface by raising the outer edge of the road above the inner edge at curves in order to counter-act the centrifugal force acting on the vehicle when it takes the curve at speed, and thus prevent the fast moving vehicles from skidding outward.

2. If oc is the angle of super-elevation required (Fig.20) for a vehicle moving at a speed of v metres (ft) per second on a curve of radius R m (ft.).

$$\tan\alpha = \frac{v^2}{R\,g}$$

Where g is the acceleration due to gravity = 9.81 m (32') per sec.

If the speed is expressed in V km/hour $\left(v = \frac{V}{3.6}\right)$

$$\tan\alpha = \frac{V^2}{127\,R}$$

The formula generally adopted is however

$$\tan\alpha = \frac{V^2}{200\,R}$$

$$\left(\text{m.p.h.},\ V = \frac{22}{15}\,V\right)$$

$$\left(\tan\alpha = \frac{V^2}{15\,R}\right)$$

$$\left(\tan\alpha = \frac{V^2}{20\,R}\right)$$

and limited to a maximum value of $\tan\alpha = 0.1$ so that the slow-moving vehicles may not overturn at such heavy cross-slopes.

Where the calculated super-elevation, therefore, exceeds this value, a super-elevation of tan = 0.1 is provided, and the speed of vehicles is limited to

$$v = \sqrt{200 \times R \times 0.1} = \sqrt{20\,R}\ \text{km/hr}$$

$$\left(V = \sqrt{2\,R}\ \text{m.p.h.}\right)$$

4. If e is the superelevation in metres (feet) by which the outer edge of road is to be raised above the inner edge, then

$$e = w\tan\alpha,$$

where w = width of road in metres (feet).

5. Example:-- Calculate the super-elevation to be provided on a 3m (10') wide road at a curve of radius 20m (60') for vehicles moving at a speed of 30 km hour (20m p.h.)

$$\tan\alpha = \frac{V^2}{200\,R} = \frac{30 \times 30}{200 \times 20} = \frac{9}{40}$$

$$\left(\tan\alpha = \frac{V^2}{20 \times R} = \frac{20 \times 20}{20 \times 60} = \frac{1}{3}\right)$$

But maximum permissible $\tan\alpha = 0.1$

and hence a super-elevation of $e = w \times \tan\alpha = 3 \times 0.1 = 0.3$ m $= 30$ cm. $(10 \times 1 = 1')$ is provided and the speed of vehicle is limited to $\overset{10}{\sqrt{20\,R}} = \sqrt{20 \times 20} = 20$km/h. $(\sqrt{2 \times R} = \sqrt{2 \times 60} = \sqrt{120} = 11$ or 10 m.p.h.)

6. Super-elevation should be provided at all sharp curves in the road by raising the outer edge of the road by half the required amount above the centre-line of the road, and by lowering the inner edge as necessary.

This permits of keeping the formation level of the road along the centre-line unchanged.

7. The adverse camber on the road is eliminated in a short length of about 20 m (60') on the tangent on either side of the circular curve.

23. Widening of Road at Curves

1. When a vehicle takes a curve, the rear wheels do not follow the path of the front wheels, and to allow for this slow of the vehicle, the road should be widened on the inside of curves, Fig.21. The extra width d metres (d ft.) required at the centre of the curve depends upon the wheel-base (distance L metres (L feet) of rear axle from the front axle) of the vehicle using the road, and also on the radius R metre, (R feet) of the curve and is given by the formula.

$$d = \frac{L^2}{2\,R} + \frac{6}{\sqrt{R}} \qquad \left(d = \frac{L^2}{2\,R} + \frac{35}{\sqrt{R}} \right)$$

Thus for a standard lorry with a wheel base of 3.4 m (11'3") the extra width required for a curve of radius 15 m (50').

$$d \; \frac{3.4^2}{2 \times 15} + \frac{6}{\sqrt{15}} = 1.94 \text{ or } 2 \text{ m}$$

$$\left(d \neq \frac{11.25^2}{2 \times 50} + \frac{35}{\sqrt{50}} = 6.25, \text{ say } 6\tfrac{1}{2}'\right)$$

2. The following table gives the extra widths recommended at curves:-

Radius in metres	0--100	100--200	200--300	300--500	500
Extra width in metres.	1.2	1.0	0.60	0.30	0

Indian Road Congress Recommendations on road curves are

(a) Super-elevation is to be worked out from the formula

$$\tan\angle\ \frac{3}{80}\ \frac{V2}{R}$$ subject to a maximum of $\frac{1}{15}$

(b) Extra widths are to be provided at curves as follows:

Radius in feet	0' to 200'	to 500'	500' to 1000'	1000' to 1500'	Over 1,500'
Extra width in feet.	4	3	2	1	0

24. Retaining and Breast Walls

1. The Retaining wall is a wall constructed to support an earth-filling with a surface slope much steeper than its natural angle of repose. Fig. 22. The abutments, abutment returns, and wing walls of culverts and bridges, the curtain and drop walls of causeways, the walls erected on down-hill sides of hill roads to support the embankment, etc. are some of the examples of retaining walls.

2. A breast wall, on the other hand, is a wall constructed on the up-hill side of a road cutting, to support the extra thrust caused by the changes in the angle of repose of the soil due to changes in the humidity of the atmosphere. Thus breast wall is similar to the retaining wall but smaller in dimensions. Also whereas a retaining wall has generally got a vertical back and a face batter, or back and face battered to opposite directions, a breast wall has both faces battered in the outwards direction Fig. 23.

3. A retaining wall becomes necessary.

(a) Where an embankment would be of excessive length in cross section due to the natural ground slope being the same as or greater than the angle of repose of soil.

(b) at all re-entering curves, where a cross drain is necessary to allow the up-hill drainage water to cross the road.

(c) on the edge of precipitious places where there is no room for an embankment.

(3) where a wall would otherwise be cheaper than a bank, such as in hard rock.

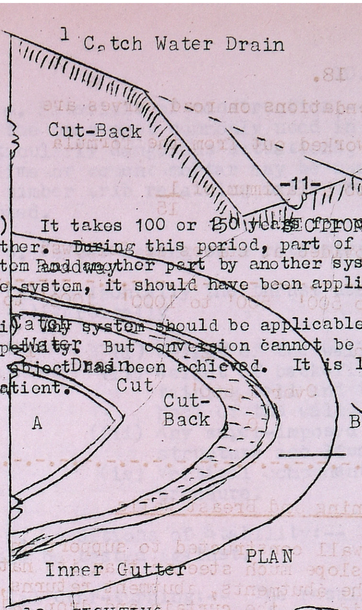

1
Catch Water Drain
Cut-Back
-11-
SECTION
Roadway
Catch Water Drain
Cut
Cut-Back
A
PLAN
Inner Gutter

Fig.19 SIGHTING DISTANCE

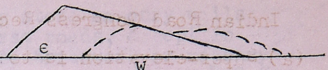


Fig.20 SUPER-ELEVATION

(ii) It takes 100 or 150 years for conversion from one system to another. During this period, part of the forest is worked by one system and another part by another system. If conversion is a separate system, it should have been applied to the entire area.

(iii) Any system should be applicable to a particular forest in perpetuity. But conversion cannot be applied as it is given up once the object has been achieved. It is like an operation carried for a patient.

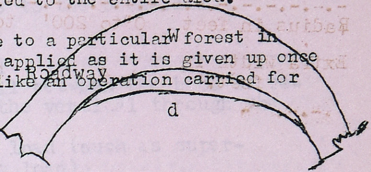

W
Roadway
d
B

Fig.21 WIDENING OF CURVES

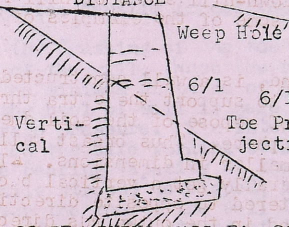

Weep Hole
6/1
Verti-
cal

Fig.22 RETAINING WALL

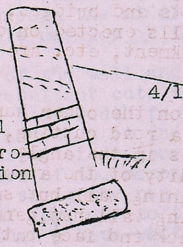

4/1
6/1
Toe Pro-
jection

Fig.23 BREAST WALL

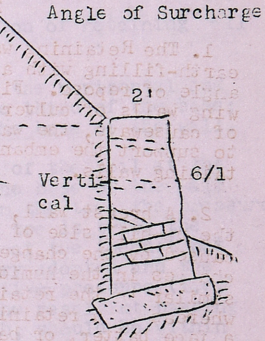

Angle of Surcharge
2'
6/1
Verti-
cal

Fig.24 SURCHARGED RETAINING WALL.

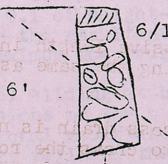


Fig.25 RETAINING WALL 6 FEET HIGH

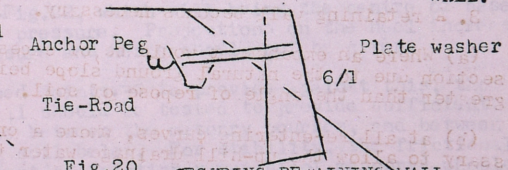

Anchor Peg
Plate washer
6/1
Tie-Road

Fig.20 SECURING RETAINING WALL

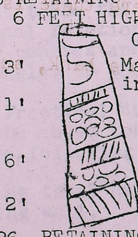

G
3'
1'
6'
2'
Masonry in mortar band

Fig.26 RETAINING WALL 12' and above

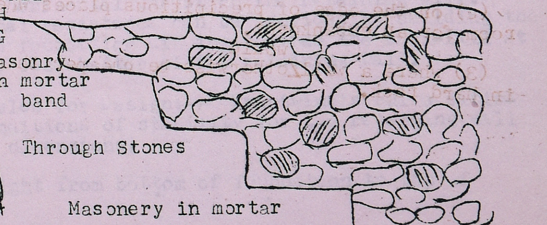

Through Stones
Masonery in mortar

Fig.27 STEPPING RETAINING WALL

4. Materials of construction,-- Dry stone masonry walls are the ones most commonly used in forest roads, except in particularly dangerous situations, where brickwork or masonry in lime or cement mortar may be used. Mass concrete or R.C.C. and timber crib retaining walls are other types of sometimes adopted.

5. Forces acting on a retaining wall are:-

(a) Horizontally the thrust due to the back-fill.
(c) Vertically

(i) Weight of the wall
(ii) Weight of back-fill between the back of retaining wall and the vertical through the heel of the wall.
(iii) Any super-imposed load (such as superstructure and live load)
(iv) Vertical component of surcharged back-fill pressure.

6. Conditions of Stability:-- The section of retaining wall should be tested against.

(a) Over-turning:-- The resultant R of the horizontal and vertical forces must pass through the middle third of the base; otherwise tensile forces would develop at the base of the wall.

(b) Crushing of the toe of the wall and of the soil at the toe of the wall. When the resultant cuts the base of the wall at the minimum distance of $\frac{1}{3}$ base-width from the toe, the pressure at the heel of wall is zero and that at the toe is twice the average pressure. The intensity of pressureat the toemust not exceed the safe working stress of the masonry adopted and the Safe Bearing Capacity of the soil; the negative pressure (i.e. tensile stress) developed, if any, due to the resultant passing nearer the toe of the wall than $\frac{1}{3}$ base-width, should be within the safe tensile stress of the masonry.

The toe pressures can be reduced by giving a toe-projection up to 0.1 of height-Fig.22, which will bring the centre of base nearer the resultant pressure. Projections on the heel increase the maximum toe-pressure and hence should not be given.

(c) Sliding at bed joints:-- To provide against this, the dimensions of the wall should be tested to provide sufficient frictional resistance between the masonry courses, and between masonry wall and the soil below. For stability, the frictional resistance (coefficient of friction x weight of masonry) should be at least twice the horizontal thrust on the retaining wall. Additional frictional resistance can be provided by building the masonry courses and foundation dipping towards the back-fill at right angles to the face batter of the retaining wall.

7. Practical Rules for Design:-- Trautwine's rules satisfying the above conditions of stability for the retaining wall give the following dimensions.

If H= total height from bottom of foundation to top of retaining wall.

Type of retaining wall	Top width	Base width	Width of foundation	Face Batter	Remarks
First Class rubble masonry or Mass concrete.	0.175 H	0.35 H	0.52 H	6/1	
Good common rubble or brick in mortar	0.20 H	0.40 H	0.60 H	6/1	
Dry stone masonry	0.25 H	0.50 H	0.75 H	4/1	
Timber crib	2m	0.5H+5m (2m min)	0.5 H+.5m (2m min)	4/1	

8. Surcharged Walls:-- A retaining wall is said to be surcharged (Fig.24), when the filling at the top slopes upwards The surcharge increases the pressure on the wall and its thickness must, therefore, be increased.

This extra pressure can be allowed for by increasing H as follows:--

Increase in H to Allow For Surcharge

Slope of ground (horizontal to vertical)	Increase factor
½ to 1	1.70 H
1½ to 1	1.50 H
2 to 1	1.45 H
3 to 1	1.30 H
4 to 1	1.25 H

9. Construction:-

(i) The excavation for foundation bed should be made dipping towards the back-fill at right angles to the face-batter, and the courses of masonry will dip inwards to strengthen the wall again slipping.

(ii) A toe-projection of 0.1 of height may be given to reduce toe pressure, and these courses are always built of masonry or brick-work in mortar.

(iii) Long through stones or headers should be used at regular intervals of 2 m (6') suitably staggered, to give a good bond. If through stones cannot be obtained, the headers may overlap 15 cm (6") in the middle.

(iv) The back of the wall should be left rough and the back-fill should be laid dry in layers, the best material being rough stones, shingles, large gravel, sand murum, etc., so that the crevices, are not choked by soil.

(v) No week holes are necessary for dry stone walling, but in masonry walls weep holes 8 x 15 cm (3" x 6') may be provided every 2 m (6') horizontally and vertically, the alternate rows being mid-staggered.

(vi) The lower course of dry stone retaining walls may be built in mortar act as foundation, but masonry or brick retaining walls must have lime concrete or cement concrete (1:4:8) foundations. The foundation must be carried deep enough below the ground level as obtained by Rankine's formula subject to a minimum 1 m (3') and its thickness may be $0.1 H + 0.30$ m.

(vii) The top width should be half the base width, subject to a minimum of 50 cm (1'6") in masonry or brick work, and 60 cm (2'0") in dry-stone walling.

(viii) Dry stone wall up to 2m (6') height may be built entirely of dry rubble stone, with a top-width of 60 cm (2'0") vertical back, and a face batter of 4/1 Fig. 25.

(ix) Dry stone walls of 2 to 4 m (6 to 12 feet) height should have their bottom 50 cm (2') built in mortar and a 30 cm (1') thick band of masonry in mortar at a height of 2 m (6') above that Fig. 26.

(x) Walls higher than 4 metres (12') should have their bottom course built of masonry in mortar with a vertical back and face batter of 6/1, and the top 4 metres (12') built in dry rubble stones with a 30 cm (1') masonry band in the middle, having a face batter of 4/1.

(xi) It would be better to have the retaining walls higher than 4 metres (12') built entirely of masonry or brickwork in mortar with a face batter of 6/1 to 8/1.

(xii) When a retaining wall is to be built to support a road crossing a small ravine, as at a re-entrant on a steep hill-side, the ends of the wall should be stepped or benched into the banks to conform to the ground levels. The foundation course should, however, be kept horizontal, Fig.27.

10. Timber Crib Retaining walls may be used in Forest works where timber is available in plenty.

(i) Minimum top width should be 2 metres (7').

(ii) Base-width == $0.5 H + .50$m ($0.5 H + 2'$), subject to a minimum of 2m (7').

(iii) Batter on both faces 4/1.

(iv) Spacing between the headers and also between the streetchers may be 1 metre (3') centre to centre. The internal headers and stretchers should be laid vertically above one another.

(v) About 10% of the headers should be of long timbers, butted into the back-fill for good bond.

(vi) The joints in the stretchers should not come vertically [illegible] above or horizontally behind each other respectively. The should be suitably staggered.

(vii) Cribs must be built in lifts of not more than 60 cm. (2') at a time to ensure that the packing (loading) is well consolidated. Clean rubble stone should be hand-packed around the timbers as each lift is completed.

(viii) The filling behind the crib should all be laid in 20 cm (8") layers and consolidated in 60 cm (2') lifts as the erection of the crib proceeds.

(ix) Timbers used may be of 15 cm (6") diameter, and must over-lap at least 50 cm (18") where necessary.

11. Breast walls:-- These are built similar to the retaining walls, their purpose being to arrest the slipping of the exposed soil from a hill-side cutting. It is advisable to increase the height of the breast wall above the edge of the cutting, so that any rolling stones or debris may be arrested and prevented from falling on the road Fig.13.

Generally they are provided with a face batter of 4/1 to 2/1 and a back batter of 6/1 to 3/1, and the base and masonry courses built perpendicular to the face batter, Breast walls should be properly drained through a sufficient number of week hopes suitably staggered.

12. Causes of failure of Retaining walls:--

(1) Settlement at the toe of the wall due to too shallow foundation, presence of water at the toe causing scour, or no toe-projection being given, so that the soil shows signs of yielding under excessive load.

(2) Lack of proper-drainage:-- If sufficient number of weep-holes are not provided, the back-fill gets saturated with water and increases the thrust on the wall, causing it to bulge out.

(3) Carelessly dumped back-fill resulting in improper drainage.

(4) Insufficient binding in masonry courses due to the absence of through and bond stones, and may also be due to weak mortar.

(5 Masonry courses, being not built perpendicular to the face batter.

13. Strengthening of Retaining walls:-- If a retaining wall shows signs of bulging out, it may be strengthened by digging out the back-fill, stepping back the natural ground, and relaying the back fill in layers with rubble or shingle backing to the wall, and providing weep holes. Anotheremethod will be to pass tie roads through the wall and securing them to anchorages placed well back in the natural ground. Fig.28.

If the toe of a wall shows signs of slipping, concrete blocks or wooden pickets may be driven into the ground in front and below the footings.

If the soil at toe is being eroded by water, dry stone revetting at the toe will prevent further erosion.

SECTION 4. PREPARATION OF A ROAD ESTIMATE

---

25. General

1. The various items involved in the construction of a road are:--

(i) The preliminary work of reconnaissance, aligning and preparation of the drawings and estimates.

(ii) Clearing of jungle growth and uprooting of trees and bamboo clumps.

(iii) Earthwork in cuttings and embankments, including blasting of rock.

(iv) Masonry works such as irish bridges culverts and bridges, retaining and breast walls, etc.

(v) Surface dressing to provide the necessary camber, superelevation, etc.

(vi) Metalling, where required, including solding, wearing, blinding and sealing courses.

2. The alignment, preparation of the drawings and estimates are generally asked to be carried out by the territorial Officer and his subordinates, unless it is a large road project, and hence no separate provision is made for this work.

3. As already stated, the alignment should be kept on government land, even at the expense of a slightly longer route, in order to avoid the cost of land acquisition. If it is unavoidable, the area of land to be acquired should be given in areas or hectares (acres), together with the current local price per are or hectare (acre).

26. Clearing the Roadway

1. Jungle Clearing:-- It is usual to make a rough estimate for each kilometre (mile or furlong) length of clearing; the rate paid for jungle clearing includes felling of all trees under 60cm (2 feet) girth, and clearing of all small bamboos and undergrowth.

2. Uprooting of trees and bamboo clumps:-- Standing trees are enumerated in the usual girth classes and auctioned, stipulating a condition that trees within the actual road width [illegible]

the side drains must be grubbed out by the root. The rates should include grubbing out the trees and bamboo clumps by the root and removal of all timber and roots to a distance of 10m (33 feet) away from the edge of the road.

A rough average cost per stump may be worked out from the local rates, and then it will only be necessary to record the number of stumps to be uprooted.

3. In Wet areas, it is usually necessary to clear the undergrowth to a distance of 3 to 5 m (10 to 15') on both sides of the road in order to let in the Sun and air to keep the road-surface dry.

In Dry zones, on the other hand, trees are necessary to shade the road.

In Sandy places, the vegetation actually helps to retain moisture, and the sides of the road should never be cleared, as sand makes a much better and harder surface when moist.

On Steep Hill-sides, a wide clearing is undesirable, as the tree-roots and under-growth hold up the soil and prevent erosion. On the up-hill side of the road, and on both sides of deep two-sided cuttings, over-hanging trees and trees which are likely to fall later should be cleared.

27. Earthwork

1. Earthwork is comparatively cheap and hence lengths may be measured to the nearest deci-metre, and widths and heights to the nearest 5 cm.

2. Areas:-- The different shapes of cuttings and embankments usually met with in road cross-sections, and formulae for determining their areas from field data are shown in Fig. 29 to 32.

3. Area of triangular section (Fig.29) may be calculated from the simple relation.

Area = $\frac{1}{2}$ base x altitude.

The altitude may be measured from the cross-section drawing.

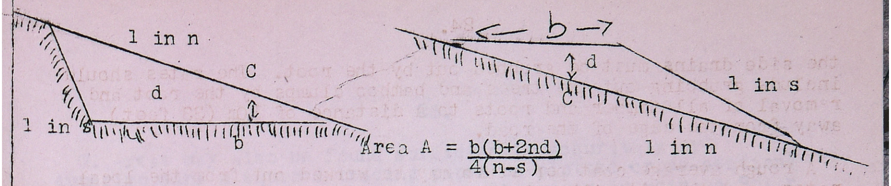
4. Area of a trapezium section (Fig.30), can be calculated from the formula

Area = $\frac{1}{2}$ (Top width + Bottom Width) x altitude.

5. Area of the two-level section (quadrilaterals Fig.31) can be easily found by dividing it into two triangles, measuring the diagonal and the two altitudes against the diagonal line as base.

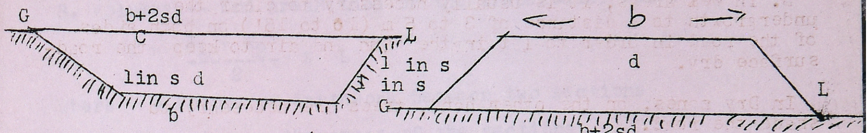
Area = $\frac{1}{2}$(diagonal) x (sum of the altitudes).

6. Area of Part-cutting and Part-embankment section (Fig.32) can be found by measuring the altitudes against base line, and also the portions of the base in cutting and embankment, and then calculating the areas of the two triangles separately.


1 in n
C
d
1 in s
b
b
d
C
1 in s
1 in n

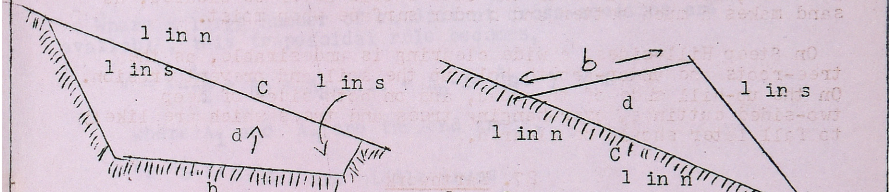
Area $A = \frac{b(b+2nd)}{4(n-s)}$

Fig.29 TRIANGULAR SECTIONS


G
b+2sd
C
L
1in s d
1 in s
in s
b
G
b
d
L
b+2sd

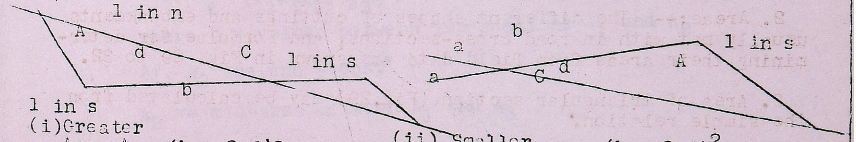
Area $A = d(b + sd)$

Fig.30 TRAPEZODIAL SECTIONS


1 in n
1 in s
C
1 in s
d
b
b
d
1 in s
1 in n
C
1 in n

Area $A = \frac{b^2s+4n^2d(b+sd)}{4(n^2 - s^2)}$

Fig.31 TWO-LEVEL SECTIONS


1 in n
A
d
C
1 in s
b
1 in s
b
a
1 in s
a
C
d
A

(i) Greater Area $A = \frac{(b + 2nd)^2}{8(n-s)}$

(ii) Smaller area $a = \frac{(b - 2nd)^2}{8(n - s)}$

Fig.32 PART CUTTING & EMBANKMENT SECTIONS

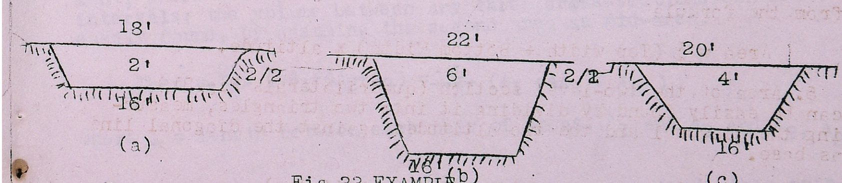
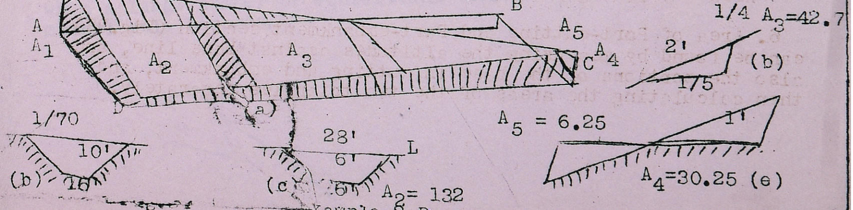

18'
2'
2/2
16'
(a)
22'
6'
2/2
16'
(b)
20'
4'
16'
(c)

Fig.33 EXAMPLE 1 PAGE


A
A1
A2
A3
B
A5
C A4
D
(a)
1/4 A3=42.7
2'
1/5
(b)
1/70
10'
16
(b)
28'
6'
L
26'
(c)
A2= 132
A5 = 6.25
1'
A4=30.25 (e)

Example 2 Page

7. Areas may also be found sufficiently accurately by superimposing a squared tracing paper on plotted cross-sections and counting the number of squares enclosed or by using a Polar Planimeter.

8. Volumes:-- End areaMethod or the trapezodial rule:

$$V = \frac{A_1 + A_2}{2} \times L$$

where V = Volume of earthwork between two sections

A_1 and A_2 = the areas of the sections,

and L = length between the two sections.

Where a large number of equdistant cross-sections are available, this trapezoidal rule becomes,

$$V = \left(\frac{A_1}{2} + A_2 + A_3 \ldots\ldots + A_{n-1} + \frac{A_n}{2} \right) \times L$$

where A_1 and A_n are the end areas,

A_2 A_3.... A_{n-1} are middle areas

L == the constant distance between each pair of areas.

9. Prismoidal formula:--

$$V == \frac{1}{6} (A_1+4A_2+ A_3)$$

where V = volume between two sections A_1 and A_8

A_1, A_3 are end areas.

A_2 == mid-area between A_1 and A_3

L == Length between A_1 and A_3

This can be very conveniently used for finding volumes of earthwork involved in a road or railway cutting or embankment, where a large number of cross-sections are taken at equal intervals; the volume between any three cross-sections can be easily found, by assuming the second area as mid-area.

$$\text{Then } = \frac{2L}{6} (A_1+4A_2+A_3) = \frac{L}{3} (A_1 +4A_2 + A_3)$$

where L = length between each pair of areas, A_1 and A_2 and A_2, A_3

when a large number of equidistant areas are involved, this prismoidal rule becomes.

$$V = \frac{L}{3} (A_1 + 4A_2 + 2A_3 + 4A_4 + 2A_5 \ldots + 2A_{n-2} + 4A_{n-1} + A_n)$$

where A_1 A_2.... An are consecutive areas of cutting (embankment) at equal distances of L metres (ft.)

or $V = \frac{L}{3}$ (Sum of end areas + 4 times the sum of even areas + twice the sum of other odd areas)

Only, n here should be an odd figure. If there are even number of cross-sections n, volume between the first "n-1" sections can be found by prismoidal rule, and that between the last pair by end area method, and the two added together.

10. The volumes of cuttings and embankments should be found separately since rates differ considerably.

11. The end area method gives slightly greater volumes and is generally used for preparing estimates. The prismoidal formula should be used for measuring earthwork for payment, since that gives more accurate results.

12. Example 1: A road is taken level in cutting with a bottom width of 16' and side slopes of 2 vertical to 1 horizontal. The depths of cutting along the centre line of the road at 100 feet intervals are 2, 6 and 4 feet. Assuming that the ground is level across the road, calculate the amount of earthwork involved.

Fig 33-a) $A1 = \frac{18+16}{2} \times 2 = 34$ sft.

Fig.33-b) $A_2 = \frac{22+16}{2} \times 6 = 114$ sft.

Fig.33-c) $A_3 = \frac{20+16}{2} \times 4 = 72$ sft.

By End area method, $V = \frac{34+114}{2} \times 100 + \frac{114+72}{2} \times 100$

$= 100 \left(\frac{34}{2} + 114 + \frac{72}{2} \right) = 100 (17+114+36)$

$= 100 (17+114+36)$

$= 100 \times 167 \quad = 16,700$ cft.

By Prismoidal rule, $V = \frac{100}{3} (24+4 \times 114+72) = \frac{100}{3} (34+456+72)$

$= \frac{100}{3} (562) = 100 (187.33)$

$= 18,733$ cft.

To face Page 28

Example 2. ABCD is a section of road on which cross-sections A_1, A_2, A_3 etc. are taken at equal intervals of 100 feet each.

From A_1, to A_3 the road is entirely in cutting, and beyond that it is partly in cutting and partly in embankment. The width of the formation is 16 feet in the solid, and the side-slopes of earthwork is 1 vertical to 1 horizontal throughout. The central depths of cutting at A_1, A_2 A_3 and A_4 and 10,6,2 and 1 foot respectively, and the natural slopes of the side-long ground at A_1,A_2,A_3 and A_4 are respectively 1 in 70 level, 1 in 4 and 1 in 5. Calculate the amounts of earthwork involved.

Fig.34a gives an isometric view of the earthwork.

	Cutting	Embankment
(Fig.34b)	$A_1 = 260.1$ sft.	0
(Fig.34c)	$A_2 = \frac{16 \text{ x } 28}{2} \text{ x } 6 == 132$ sft.	0
(Fig.34d)	$A_3 = 42.7$ s.ft.	0
(Fig.34e)	$A = 30.25$ s.ft.	$A_5 = 6.25$ s.ft.

$$\text{Cutting V } A_1 = A_3 = \frac{100}{3}(260.1 + 4\text{x}4\ 132 + 42.7) = 27{,}693 \text{ cft.}$$

$$\text{Cutting V } A_3 - A_4 = \frac{42.7+30.25}{2} \text{ x } 100 = 3647 \text{ cft.}$$

Total earthwork in cutting = 27693 + 3647 = 31,340 cft.

$$\text{Embankment V} = \frac{0+6.25}{2} \text{ x } 100 = 312.5 \text{ cft.}$$

Example 3. A road is 20 feet wide at the formation level with side-slopes $1\frac{1}{2}$ horizontal to 1 vertical. Estimate the earthwork in a portion of the road with the following data, assuming the ground to be fairly level across the road:-

Chainage ft.	0	100	200	300	400	500	600
Ground level ft.	90	94	97	101	104	104	106
Formation level ft.	96	97	98	99	100	101	102

Draw a longitudinal section (Fig.35) which shows an embankment of 6,6,4 and 2 feet at chainages 0 to 300', and a cutting of 1,3 and 4 feet from 400' to 600'. Hence, the cutting changes to bank between 300' and 400' at a point A.

$$\text{Such that } \frac{AB}{AC} = \frac{BE}{CD} \text{ or } \frac{AB}{(BC - BA)} = \frac{BE}{CD}$$

or $\frac{AB}{100-AB} == \frac{2}{1}$ or AB x 1 = 200 -- 2AB or 3 AB = 200

or AB = $\frac{200}{3}$ = 66.7 ft. or 67 ft. and AC = 100--66.7==33.3 or 33 ft.

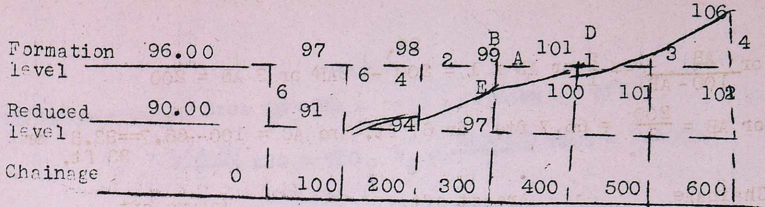
Chainage ft.	Areast sft.	Volume cft.
0	$A_0 = \frac{20+38}{2} \times 6 = 174$	$V_1 = \frac{174+174}{2} \times 100 = 17400$
100	$A_1 = \frac{20+38}{2} \times 6 = 174$	$V_2 = \frac{174+104}{2} \times 100 = 13900$
200	$A_2 = \frac{20+32}{2} \times 4 = 104$	$V_3 = \frac{104+46}{2} \times 100 = 7500$
300	$A_3 = \frac{20+26}{2} \times 2 = 46$	$V_{3-A} = \frac{46+0}{2} \times 67 = 1541$
367	$A_A = \frac{20+20}{2} \times 0 = 0$	Total cutting 39441 cft.
400	$A_4 = \frac{20+23}{2} \times 1 = 21.5$	$V_{A4} = \frac{0+21.5}{2} \times 33 = 355$
500	$A_5 = \frac{20+29}{2} \times 3 = 73.5$	$V_5 = \frac{21.5+73.5}{2} \times 100 = 4750$
600	$A_6 = \frac{20+32}{2} \times 4 = 104$	$V_6 = \frac{73.5+104}{2} \times 100 = 8875$
		Total embankment: 13980 cft.

Example: 4 - The longtitudinal section of a proposed road is shown in Fig.37. Calculate the volume of earthwork in cutting, assuming that the ground is level at right angles to the L.S. Bottom width of cutting is 16 feet and side slopes are 1:1

Form the gradients along ground, calculate the differences in level and the reduced levels of ground, and write them on the L.S. -- 100, 110, 106, 104 and 114 feet respectively.

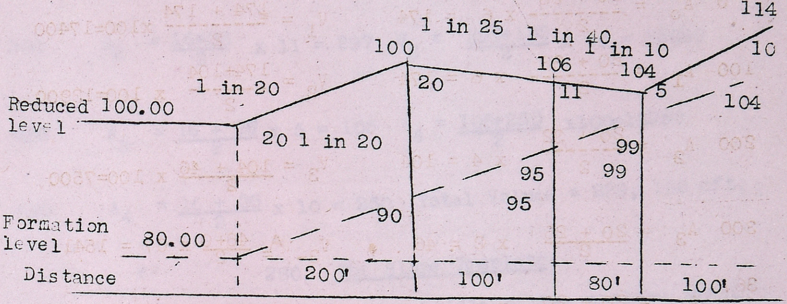
Then from the proposed gradients of road, calculate the levels of formation and write them also on the L.S. -- 80, 90, 95, 99 and 104 feet respectively. There differences between the two pairs of levels give the depths of cutting at the different points -- 20, 20, 11, 5 and 10 feet respectively. Then

To face Page 28



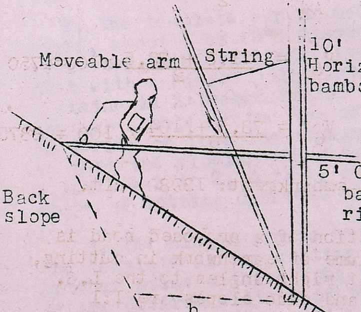
Formation level
96.00
97
98
2
99
B
A
101
D
1
106
4
3
6
4
6
E
100
101
102
Reduced level
90.00
91
94
97
Chainage
0
100
200
300
400
500
600

Fig.35 EXAMPLE 3 PAGE



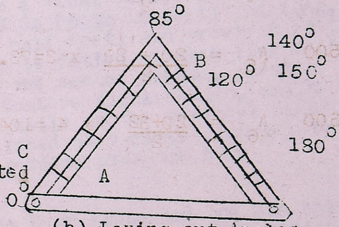
1 in 25
1 in 40
114
100
1 in 10
10
106
104
1 in 20
20
11
5
104
Reduced level 100.00
20 1 in 20
99
95
99
95
90
Formation level
80.00
Distance
200'
100'
80'
100'

Fig.36 EXAMPLE @, PAGE



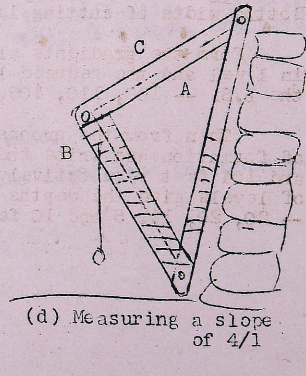
Moveable arm
String
10' Horizontal bamboo
5' Graduated bamboo ring
Back slope
b

Fig.37 The SLOPE TEMPLATE

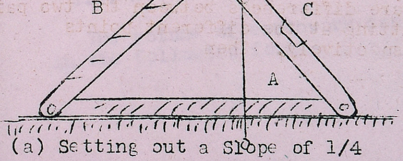


85°
140°
B
120°
150°
180°
C
0°
0
A

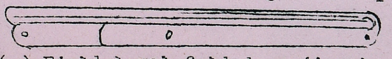
(b) Laying out Angles



(d) Measuring a slope of 4/1



(a) Setting out a Slope of 1/4



(a) Field level folded up 4' rule

Fig.38 USES OF A FIELD LEVEL

Chainage	Area in sft.	Volume in cft.
0	$A_o = \frac{16+56}{2} x20 = 720$	$V_1 = \frac{720+720}{2} x200 = 144000$
200	$A_1 = \frac{16+56}{2} x 20 = 720$	$V_2 = \frac{720+297}{2} x 100 = 50850$
300	$A_2 = \frac{16+38}{2} x 11 = 297$	$V_3 = \frac{297+105}{2} x 80 = 16080$
380	$A_3 = \frac{16+26}{2} x 5 = 105$	$V_4 = \frac{105+260}{2} x100=18250$
480	$A_4 = \frac{16+36}{2} x 10 = 250$	Total Volume = 229, 180 cft.

280. The Slope Template.

1. For narrow hill roads, like bridle paths, a slope template Fig.27 may be used to measure earthwork involved in triangular cuttings.

2. The template can be made from a stout vertical bamboo staff, about 5 cm (2") diameter and 3m (8 to 10 feet) and long, graduated in 20 cm links (feet and half feet) and provided at its feet with a hinged joint into which is fitted another long bamboo. A string is attached to the top of the second bamboo, passed through a hole in the top of the stout vertical bamboo, ending in a ring or loop for hooking over nails on the vertical bamboo. so that the sloping arm may be inclined at various slopes 1 to 1 2 to 1, 3 to 2, 4 to 1, etc., depending upon the back slope of cutting desired.

3. The hinged arm is set to the back slope and one man holds the template at the cutting edge with the graduated arm vertical, Another holds a third long bamboo horizontally with one hand at the desired width b of the road on the inclined bamboo, and slides it up or down until it touches the hill-side. The height of cutting h is then read off on the vertical bamboo, and area of earth cutting will be

$$A = \tfrac{1}{2} b \times h$$

i.e. $A = \frac{1}{2}$ width of road x height read.

The volume of earthwork can then be calculated and recorded in the following form:-

Peg No.	Distance in ft	Back slope	Width feet	Height in ft.	Area of sec. sft.	Av. area sft.	Volume of earth-work		
							Hard soil cft.	Soft soil cft.	Rock cut cft.
		Brought forward					10270	2560	960
10	[illegible]	3 in 1	12	6	36				
	100					30	3000	..	..
20		2½ in 1	12	4	24				
	100					36	2000	1600	..
21		3 in 1	12	8	48				
	100				---	39	3400	..	500
22		2 in 1	12	5	30				
		Carried over					18670	4160	1460

In the Remarks column may be made entries of jungle clearing uprooting of trees, stream crossings, retaining walls, revetments etc.

29. Masonry Works and Surface Dressing

1. Masonry works like culverts, irish bridges, retaining walls, revetments, etc., must be separately estimated and included in the abstract of cost.

2. When a cutting is less than 30 cm (1') in depth, it is usually shown as "surface dressing". This includes charges for providing the necessary camber or super-elevation as the case may be and also the digging of 30 cm (1') drainage channels on either side of the road. For cart roads in flat ground, the earth obtained from excavation of the side ditches should be thrown on to the middle of the road to obtain the required camber. A rate is usually fixed per 100 metre length (100 feet) or 100m (sft) of the road surface dressed.

3. When the road is to be given an improved surface such as sand or gravel dressing and metalling or corduroying, etc., their cost should also be included in the estimate. The usual method is to provide separately for the cost of collection and stacking of the material, and for spreading and consolidating them on the road formation.

30. The Estimate Form

1. A road project should consist of a report, a brief specification, an index map with detailed drawings, a detailed estimate and an abstract of cost.

2. The report should detail the necessity for and nature of the proposed road, its general direction and nature of terrain the obligatory points, traffic expected, availability of material and labour water, supply, etc.

3. A brief specification for the road, indicating the class of road, formation width, side-slopes of cuttings and banks, locations of borrow pits and spoil banks, quarries for foundation and wearing courses the types of irish-bridges, causeways, retaining walls, revetments, etc. should be attached.

4. An index map showing the location of the road, a detailed plan and longitudinal section, sheets of cross-sections showing areas of cutting and filling, detailed drawing of all masonry works required, such as, irish bridges, culverts, retaining walls, revetments, etc. should be enclosed.

The Detailed Estimate of quantities of earthwork, jungle-clearing, etc., should be prepared in the form appended below:--

Vide separate sheet ~~for~~ to face page No.31

Abstract of Cost

Mohand Road Project

@@@@@

Item	Quantity	Details of work	Rates Rs. P.	Per	Cost Rs. P.	Remarks
		Clearing:--				
1.	7100 rft.	(a) Jungle clearing	0.40	100rft	28.40	
	134	(b) Uprooting trees	0.25	each	33.50	
	27	(c) Uprooting bamboo clamps	1.00	"	27.00	88.90
		Earthwork:--				
2.	39475 cft	(a) Cut in hard soil	20.00	1000 cft	789.50	
	99369 cft	(b) Cut in Bouldery soil	15.00	"	1490.54	
	22350 "	(c) Rock blasting	25.00	"	558.75	
	53200 "	(d) Embankment	5.00	"	266.00	
						3104.79
		Drains:--				
3	500 rft.	(a) Catch water drains area 4 sft.	6.00	100rft.	30.00	
4	10000 "	(b) Side drains area 1¼ sft.	1.00	100rft.	100.00	
						130.00

@@@@ 6. An Abstract of cost is then prepared from the summaries of the detailed estimate as per example below, after adding a 5 per cent extra for contingencies to cover some unforeseen minor items of work.

		Culverts:--				
6		(a) Stone slab (4'span)	250.00	each	1500.00	
		(b) Arch culvert (10'span)	500.00	"	500.00	
		(c) Concrete pipe				
		(d) Timber culvert		"		2000.00
		Retaining walls:-				
		(a) Dty Stone	60.00	100 cft		
		(b) Stone in the mortar 1:2	80.00	"		
		(c) Stone in cement Mortar 1:4	90.00	"		
6	71000 sft.	Sectioning and surface dressing (earth road)	0.10	100 sft	71.00	71.00
7.		Metalling:-				
		(a) Soling		100 cft.		
		(i) Collection and stacking		"		
		(ii) Laying and consolidation		"		
		(b) Wearing Course		"		
		(i) Collection and stacking		"		
		(ii) Laying and consolidation		"		
		(c) Blinding		"		
		(i) Collection and stacking		"		
		(ii) Laying and consolidation		"		
		(d) Sealing cost		"		
		(i) Collection and stacking		"		
		(ii) Laying and consolidation		L.S.		
8		Water Supply:-				
9		Mile and furlong Stones, etc.:-				
	2	(a) Mile stone (Pickets)	3.00	each	6.00	
	10	(b) Furlong stone (Pickets)	2.00	each	20.00	
	100	(c) Guard stone	1.00	each	100.00	
	1	(d) Sign Posts	10.00	each	60.00	
					-------	136/-
		Total:			5530.69	
		Contencies 5%			278.31	
		Grand total			3809.00	

-.-

SECTION 37. SETTING OUT OF ROADS

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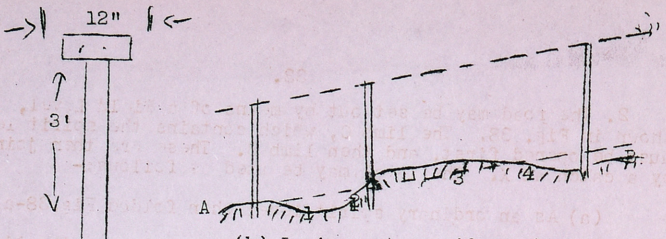
31. General

1. The data required for setting out the final alignment are taken out from the drawing and fieldbooks, and transferred to the ground by measuring out the required offsets on the pegged alignment.

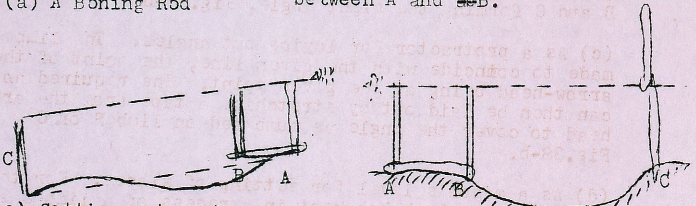
Mohand Road Project - Saharanpur Division, U.P.

Peg No.	Chainage	Distance	Area of Section		Ac. area of Sec.		Volume of earth work				Jungle	Trees	Bamboo clumps
			Cutting	Bank	Cutting	Bank	Cut in Hard soil	Cut in Bouldery soil	Blasting rock	Embankment			
	ft.	ft.	s.ft.	s.ft.	s.ft.	s.ft.	c.ft.	c.ft.	c.ft.	c.ft.	sft	No.	No.
1													
		Brought forward					33225	80119	22350	52650	6900	109	20
69	6900	~~140~~	140.0	--									
		50			148.0	--	--	7400	--	--	50	7	2
69-A	6950		156.0	--									
		50			117.0	--	--	5850	--	--	50	8	3
70	7000		78.0	--									
		50			125.0	--	6250	==	--	--	50	-	2
70-A	7050		172.0	--									
		50			120.0	11.0	--	6000	--	550	50	10	--
71	7100		68.0	20.00									
		Total					39475	99369	22350	53200	7100	134	27



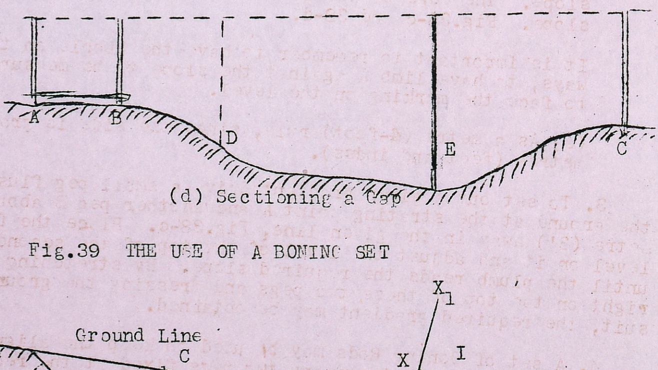
(a) A Boning Rod

(b) Laying out a uniform slope between A and ~~ab~~B.



(c) Setting out a slope

(e) When the Far bank is higher



(d) Sectioning a Gap

Fig.39 THE USE OF A BONING SET

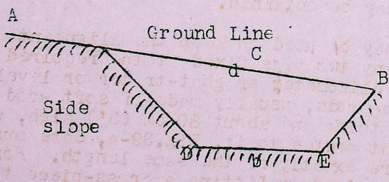

A
Ground Line
C
d
B
Side slope
D
d
E

Fig.40 SETTING OUT CUTTINGS

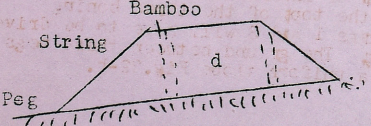

Bamboo
String
d
Peg

Fig. 41 SETTING OUT EMBANKMENTS

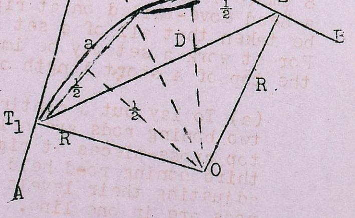

X_1
I
X
C
D
T_2
$\frac{1}{2}$
D
B
a
$\frac{1}{2}$
$\frac{1}{2}$
R
T_1
R
O
A

Fig.42 THE ELEMENTS OF A CURVE.

2. The road may be set out by means of a Field Level, shown in Fig. 38. The limb C, which contains the spirit level, must be opened first, and then limb B. These are then joined by a catch at X. The level may be used as follows:-

(a) As an ordinary spirit level when folded Fig.38-a

(b) As a square for setting out right angles, the limbs B and C forming the right angle, Fig.38-B

(c) As a protractor for laying out angles. The limb A is made to coincide with the given line, the point of the arrow-head being at the given point. The required angle can then be laid out by stretching a tape from the arrow-head to cover the angle as numbered on limb B or C Fig.38-b.

(d) As a mason's level for setting of slopes, For this purpose, the plumb bob kept in a recess of a limb C should be suspended and allowed to swing freely, the level moved until the string coincides with the required angle or slope. The edge of the limb A will then be at the required slope. Fig.38-c and 38-d.

It is important to remember to have the bubble on top always, to have limb A against the slope to be measured, and to face the marking on the level.

(e) As a metre (4-foot) rule, since one side is graduated in metres (feet and indes).

3. To set out a given gradient drive a small peg flush to the ground at the strating point A and another peg B about 1 metre (3') away in the given line, Fig.38-c. Place the field level on it and adjust the level of the top of the second peg B until the plumb reads the required slope. By stretching a string right on the top of these two pegs and dressing the ground to suit, the required gradient may be obtained.

4. A set of Boning Rods may be used to keep the alignment on a given gradient between any two pegs fixed at the required levels, either by means of a clinometer or ghat-tracer or level. A set consists of three boning rods, usually made of soft wood 8 cm (3") wide and 2 cm ($\frac{3}{4}$") thick and about 80 cm (3') high, with a head dove-tailed on at right angles to it, Fig.39-a, Care must be taken that all of a set are exactly pf the same length. For Forest work a set may be improvised by fitting a cross-piece to the top of a short length of bamboo.

(a) To lay out a continuous slope between two pegs A and B two boning rods are held vertically on A and B, with their top cross-pieces at right angles to the line AB, and a third boning roed held on tops of intermediate pegs, and adjusting their levels until the tops of the three boning rods are in one line. Thus pegs 1 and 3 will have to be driven into the ground by excavating. The ground between these pegs may then be excavated to get a uniform slope Fig.39-b.

(b) To set out a given slope, a peg A is first driven flush to the ground at the strating point and then another peg B driven about 80 cm (3') away along the given line, and its top adjusted to be at the given slope by means of the field level. Two boning roads may be placed on the tops of these pegs (Fig.39-c and a third held on top of peg at the required point C, with its top adjusted to be in line with the tops of the first two boning rods.

(c) To take the section of a stream or other gap with such rods, level the first two pegs A and B by means of the folded field level, Fig.39-d. By looking over the tops of the first two pegs, (A, B), the depth below the line of sight of any other pegs (C,D,E.) can be found by holding up a measuring rod (or graduated folding boning rod 3m (10') long opening out to 6m (20') in length at those points. Then by measuring the horizontal distances of those points from A, the section can be plotted.

If any point C happens to be above the starting point A, then the boning rod over C is held inverted against a measuring rod such that the line of sight touches bottom of Tee as shown in Fig.39-e. Then height of C above A is equal to the height of the boning rod about 80 cm (3') less the height of boning rod above peg at C.

32. Setting out Earthwork

1. Cuttings:- After setting out pegs along the alignment at the required gradients, it is marked with a pick-axe continuously. Then the bottom width of the cutting is marked on the ground by lines parallel to the centre line, since often the centre piece of earth is excavated first and then the side slopes struck.

2. The edges of the slopes must next be marked. The width of side slopes will vary with the depth of the cutting, being times the depth. These widths must be set out at each station peg, and lines run from point to point to mark the cutting edge. The simplest way to find the correct position of the cutting edge at a peg is to draw the cross section of the proposed formation at that peg to a sufficiently large scale, say 1/100 (1"==10') measure off the sloping distances of the edges CA and CB, Fig.40, at which the side slopes of the cutting meet the ground surface. These distances can then be measured off on the ground.

2. Embankment:- For setting out an embankment two bamboos are erected at distance apart equal to the top width. Fig. 41, and two pegs driven at the toes of the bank as measuring from the coross-section drawing. A stout string is then tied across the poles at the exact height of the bank and to the pegs so that the string will show the correct shape of proposed bank.

String profiles are liable to be blown down or altered by wind, and hence regular earth profiles 2 to 3 m (5 to 10') wide at top are constructed at intervals of about 200 m (500') All profiles should be frequently checked to avoid errors due to trampling, etc.

33. Setting out Road D Curves

1. General:- Curves on roads are not required to reach the degree of accuracy necessary in the location of a railway or tramway line, since the rear wheels of a vehicle need not follow the path of the front wheels. The curves are all simple arcs of a circle, and the introduction of a transition curves between the straight and the circular portions are entirely dispensed with, except in the case of important national highways, which cater for very high speeds.

A theodolite or other angular instrument may be used for setting out long curves on important main roads, but for purposes of ordinary roads, only a chain or steel tape would have to be used for setting out small circular curves. Hence, only these simple methods will be described here.

2. Elements of a circular curve:-- The Point of Intersection or vertex is the point X, Fig.42, where the two straights or Tangents AX and BX meet.

Tangent Points are the two points where the curve meets the tangents. The point T_1 where the curve begins is called the Initial Tangent Point, and the point T_2 where the curve ends is called the Final Tangent Point. The length of the tangents XT_1 and XT_2 is termed Tangent Length T.

The straight line joining the two tangent points, T_1 T_2 is called the Long Chord or Grand Chord of the curve.

Intersection Angle or Deflection Angle, 1, of the curve, is the angle X1 XT_2 representing the amount of deviation given by the curve, and is equal to the Central Angle T_1 OT_2 subtended by the long chord at the centre.

Apex of the curve is its middle point C, and CX is known as Apex Distance. Angle T_1XT_2 subtended by the long chord at the vertex is called the Apex Angle and is equal to 180° -- 1.

The perpendicular distance CD of the apex from the long chord is called Middle Ordinate or Mid-Ordinate.

Tangential Angle is the angle between the tangent at the point and the next chord XT_1 a, and is equal to half the angle subtended by that chord at the centre of the circle. The angle XT_1 T_2 = X T_2 T_1 between the straight and the long chord is known as the whole tangential angle, and is equal to half the central angle = ½ 1.

3. Nomenclature of Curves:- A curve may be designated either by the length of its Radius or by its Degree of Curvature. The Degree of a curve is the angle subtended at the centre of the curve by a standard chord (Fig.43), generally 20m (100' in the British system). Thus a 1°, 2° or 3½° curve means that a chord of 20m (100') on it will subtend an angle of 1,2 or 3½° at the centre.

Now 360° are subtended at the centre by $2\pi R$ metres (feet)

1° is " $\frac{2\pi Rx1}{360}$ metres (feet -

Hence in a 1° curve, $\frac{2\pi Rx1}{360} = 20m(100 \text{ feet})$

$R = \frac{20x360}{2x3.1416} = 1146$ metres ≬ $R = \frac{100x360}{2x3.1416} = 5730$ ft.

Thus radius of a 1° curve is 1146m (5730'), that of a 2° curve is 573 metres (2865 feet), and so on and in general, for a D^o curve.

$R = \frac{1146}{D}$ m ≬ $R = \frac{5730}{D}$ feet

Example 1. What is the radius of a 3° curve?

$R = \frac{1146}{3} = 382$ m ≬ $R = \frac{5730}{3} = 1910$ feet.

2. What is the degree of a curve of 100 metres (1000') radius?

$D = \frac{1146}{100} = 11^046$ ≬ $D = \frac{5730}{1000} = 5^073$

4. Tangent Distance½ Refering to Fig.42 from the osoceles triangle $XT_1 T_2 = XT_1 T_2 = \frac{1}{2}X_1XT_2 = T_1OX = T_2OX = \frac{1}{2}1$

Therefore $\frac{XT_1}{OT_1} - \frac{T}{R} = \tan T_1 OX = \tan 1/2$

Tangent Distance $T = R \tan 1/2$

or Radius $R = \frac{T}{\tan 1/2} = T \cot 1/2$

Example 1:- Find the tangent distance for a 2° curve joining two straights intersecting at an angle of 32°.

Radius $R = \frac{1146}{2} = 573$ m

Tangent Distance $T = 573x\tan 16^o$
$= 573x0.2868$
$= 164.34$ m

$R = \frac{5730}{2} = 2865$ feet

$T = 2865 \times 0.2868$

$= 821.5$ feet

5. Length of Curve:- Assuming that the length of the arc is very nearly equal to the length of the chord,

$$\text{Length of curve } L = \frac{\text{Central Angle}}{\text{Degree of curve}} \times 20 == \frac{1}{D} \times 20 \text{ m}$$

$$\text{Also from Fig. 43, sign } \frac{D}{2} = \frac{10}{R}$$

$$\text{and for small angles, } \sin\frac{D}{2} = \frac{D}{2} \times \sin 1^{\circ} = \frac{D}{2} \times 0.01745 = \frac{10}{R}$$

$$\text{or } D = \frac{10 \times 2}{0.01745 \ R}$$

$$\text{and } L = \frac{1}{D} \times 20 = \frac{\frac{1 \times 20}{10 \times 2}}{0.01745 \ R} = \frac{1 \times 20 \times 0.01745 \ R}{10 \times 2}$$

Therefore L = 0.01745 x 1 R metres ≬ L = 0.01745 1 R feet (1 in degrees)

Example 1: What is the length of a 5° curve with an Intersection angle (or central angle) of 60?

$$L = \frac{1}{D} \times 20 = \frac{60}{5} \times 20 = 240 \text{ metres}$$

$$L = \frac{1}{D} \times 100 = \frac{60}{5} \times 100 = 1200 \text{ ft.}$$

2. Find the length of a 50 m (200') radius curve with a central angle of 20°.

L = 0.01745x20x50 = 17.45 m ≬ L = 0.01745x20x200=69.8 feet.

6. Length of Long Chord:- From Fig.42

$$\frac{T_1D}{OT_1} = \frac{\frac{1}{2} T_1T_2}{R} = \sin T_1OD = \sin 1/2$$

$$\text{Therefore } T_1T_2 = 2 \ R \sin 1/2$$

Example 1: Find length of Long chord for a 5° curve having a central (Intersection) angle of 60°.

$$\text{Radius } R = \frac{1146}{5} = 229.2 \text{ m} ≬ \text{Radius } R = \frac{5730}{5} = 1146 \text{ feet.}$$

$$\text{Length of Long chord } T_1 T_2 = 2 \times 229.2 \times \sin\frac{60^{\circ}}{2} = 2 \times 229.2 \times \frac{1}{2}$$

= 229.2 m ≬ (I = 1146 feet)

7. Apex Distance.-- From Fig. 42,

$$\text{Apex Distance } CS = OX - - OC = \frac{OT_1}{\cos XOT_1} - - OC = R\,(\sec 1/2 - - 1)$$

Example 1: Calculate the Apex Distance for a 6° curve with a central (Intersection) angle of 32°.

$$\text{Radius } R = \frac{1146}{6} = 191 \text{ metre}$$

$$\text{Apex Distance } CX = 191\left(\sec \frac{32^\circ}{2} \quad 1\right) = 191\left(\frac{1}{\cos 16^\circ} - - 1\right)$$

$$= 191\left(\frac{1}{0.9613} - - 1\right)$$

$$= 7.697 \text{ m}$$

8. Mid-Ordinates: -- From Fig.42

$$\text{Mid Ordinate } CD = OC - - OD = OC - - OT_1 \cos DOT_1 = R - - R\cos 1/2$$

$$= R\,(1 - - \cos 1/2)$$

Example 1: Find the Mid-ordinate of a 3° curve with a central (Intersection) angle of 20°.

$$\text{Radius } R = \frac{1146}{3} = 382 \text{ m}$$

$$\text{Mid-ordinate } CD = 382\left(1 - - \cos \frac{20^\circ}{2}\right) = 382\,(1 - - 0.9848)$$

$$= 382 \times 0.0152 = 5.81 \text{ m.}$$

9. Length of Standard chord: In the formulae, it is assumed that the length of the arc is equal to that of the chord on which it stands. In order to minimise the effect of this error the length of chord used should be limited to one twentieth of the radius of the curve. It is usual to adopt 5 metre chord for radius up to 200 metres, 10 metres chords for radii from 200 to 400 metres, and 20 metre chords for curves of raddi 400 metres and over. (It is usual to adopt 10' chords for raddi up to 200', 25' chords for radii from 200 to 1000', 50', chords for radii from 1000 to 2000' and 100' chords for radii 2000' and above),

10. Methods of Laying out Curves:-- A long curve cannot be laid out on ground with any accuracy without the use of an angular instrument like at heodolite, but we can use a few useful geometrical principles for laying out short curves. The Railway or tramway curves have got to be laid out by a theodolite since high speeds and a fixed path are involved, but the following methods are of sufficient accuracy for laying out road curves, since a slew of the vehicle is permitted--

(1) Ordinates from the Long Chord.

(2) Chords and Øffsets outside curve.
(3) Versines or Mid-Ordinates.
(4) Chords and Offsets inside the curve.
(5) Radial offsets from the tangents.
(6) Perpendicular Offsets from the tangents.
(7) Parabolic curves.
(8) Vertical Curves.

The first two methods, being the ones generally used, are described below, as also the parabolic curve, which is sometimes adopted.

11. Field method of finding the Tangent Length (T):--

Fix the Intersection Point "X" and choose two points D and E on the tangents XT_1 and XT_2 such that XD = XE. Measure DE and fix its middle point, F, see Fig.44. Then

$$\text{tangent length } T = \frac{XF}{DF} \times R$$

12. Method of ordinates from Long Chord:-- We have Middle Ordinate $MC = R\,(1 - \text{Cos } 1/2)$

Length of long Chord $L = T_1 T_2 = 2\,R \sin 1/2$

Referring to Fig.45, $MC = OC - OM = OC - \sqrt{T_1O^2 - T_1M^2}$

$$= R - \sqrt{R^2 - \left(\frac{L}{2}\right)^2} = O \text{ say}$$

Ordinate at any other point Q distant x from the middle point M

$$OX = PQ = OP_1 - OM\ \sqrt{OP^2 - PP_1^{\,2}} - (OC - MC)$$

$$= \sqrt{R^2 - x^2} - (R - O)$$

Thus offsets to the curve at various points of the long chord like $\frac{L}{4}, \frac{L}{8}, \frac{L}{16}$, etc. can be calculated and the entire curve laid out on ground.

The only snag here is that the entire curve will first have to be laid out on ground and the chainage contained afterwards by measuring along the curve.

ALTERNATIVELY, the following approximate formula for finding the ordinates from long chord may be employed--

$$\text{Mid-Ordinate } O = \frac{L^2}{8\,R}$$

where L = length of long chord $T_1\ T_2$

and R = radius of the curve.

Ordinate at any other point Q, distant x from the middle point M of the long chord is given by

$$Ox = O -- \frac{x^2}{2R}$$

Example 1: Calculate the radius for a circular curve having a long chord of 100 m (100') and a Mid Ordinate of 10m (10')

From Fig.46 $O = 10 = \frac{L^2}{8R} = \frac{100^2}{8R}$

or $R = \frac{100x100}{8x10} = 125$ metres.

Example 2:. AB is a straight 80 m (200') long. A circular curve of radius 100 m (500') passed through A and B. Tabulate the offsets to the curve from the chord A B at 10 m (25') intervals. See fig. 47

Mid-Ordinate $O = \frac{L^2}{8R} = \frac{80^2}{8x100}$ Mid-ordinate $O = \frac{200^2}{8x500}$ $(200)^{-12}$

$= 8$ m. $= 10$ ft

Ordinate at 10 m from M is

$$O_{10} == 8.0 -- \frac{10^2}{2x100} = 8.0 -- 0.5 = 7.5 \text{ m}$$

$$O_{20} = 8.0 -- \frac{20^2}{2x100} = 8.0 -- 2.0 = 6.0 \text{ m.}$$

$$O_{30} = 8.0 -- \frac{30^2}{2x100} = 8.0 -- 4.5 = 3.5 \text{ m}$$

$$O_{40} = 0 \text{ m.}$$

Ordinate at 25' from M is

$$O_{25} = 100 -- \frac{25^2}{2x500} = 10.0 -- 0.6 = 9.4 \text{ ft.}$$

$$O_{50} = 10.0 -- \frac{50^2}{2x500} = 10.0 -- 2.5 = 7.5 \text{ ft.}$$

$$O_{75} = 10.0 -- \frac{75^2}{2 x 500} = 10.0 -- 0.6 = 4.4 \text{ ft.}$$

$$O_{100} = 0 \text{ ft.}$$

The following table shows chainages from A along AB and the offset to the curve from the long chord AB:

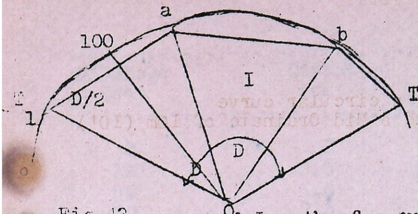

a
100
b
I
T1
D/2
T2
D
D
O

Fig.43 Degree & Length of a curve

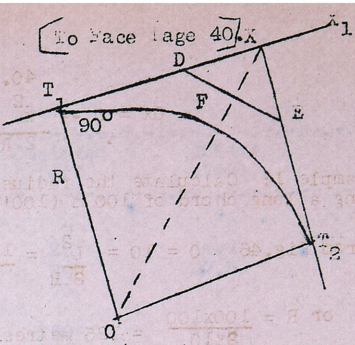

X
X1
D
T1
F
90°
E
R
T2
O

Fig.44 Tangent Lengths in the field

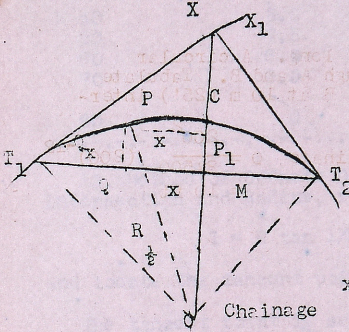

X
X1
P
C
x
x
P1
T1
T2
Q
x
M
R
½
O
Chainage

Fig.45 ORDINATES FROM LONG CHORD

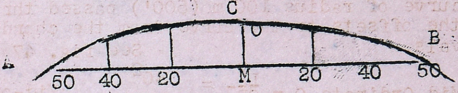

C
O
A
B
50
40
20
M
20
40
50

Fig. 46 Example 1

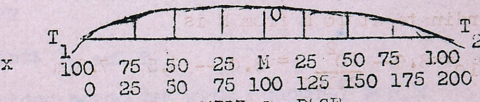
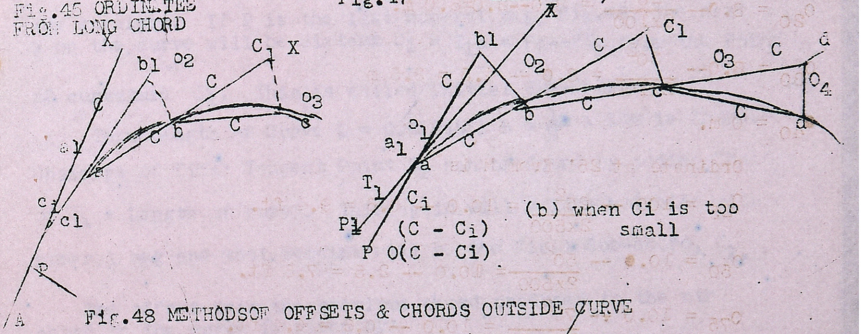

O
T1
T2
x
100
75
50
25
M
25
50
75
100
100
0
25
50
75
100
125
150
175
200

Fig.47 EXAMPLE 2, PAGE


X
b1
O2
C1
X
C
C
O3
a1
C
b
C
c
a
Ci
c1
P
A
X
b1
C
C1
O2
C
O3
C
d
C
O4
O1
b
C
c
C
d
a1
C
a
T1
Ci
P1
(C - Ci)
P
O(C - Ci)

(b) when Ci is too small

Fig.48 METHODSOF OFFSETS & CHORDS OUTSIDE CURVE

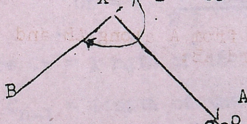


Fig.49 Example 1

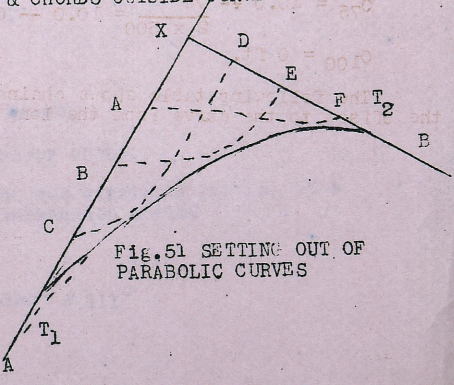

X
D
E
A
F
T2
B
B
C
T1
A

Fig.51 SETTING OUT OF PARABOLIC CURVES

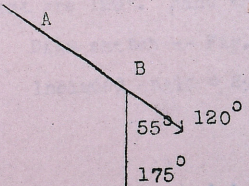

A
B
55°
120°
175°

Fig. 50 EXAMPLE 2 on Page

Chainage feet	Offset feet	Chainage feet	Offset feet
A 0	0	A 0	0
10	3.5	25	4.4
20	6.0	50	7.5
30	7.5	75	9.4
M 40	8.0	M 100	10.0
50	7.5	125	9.4
60	6.0	150	7.5
70	8.5	175	4.4
B 80	0	B 200	0

13. Method of Offsets Outside the Curve:-- From the angle of Intersection and Radius, find tangent distance,

$$I = R \tan 1/2$$

and locate the tangent points T_1 and T_2

The tangent point T_1 seldom coincides with a numeral peg on the straight. If P is the last numeral peg, Fig.48, the next peg a on the curve will be distant $C_1 = T_1a = Pa--PT_1$ from the Point of curvature T_1. This is called Initial Sub-Chord.

Then Length of Curve $L = 0.01745 \, I \, R = \frac{1}{D} \times 100$ is found. Chainage of final Tangent Point T_2 can be found by adding Chainage of T_1 + Length of curve. This again will seldom coincide with a numeral peg and what remains will be the Final Sub-chord, C_1.

The offset from the previous chord produced to the nth chord on the curve is given by

$$On = \frac{C\,(Cn+C_{n-1})}{2\,R}$$

Where Cn = length of the nth chord.

and C_{n-1} = length of the previous chord.

Example 1: The bearings of the two straights meeting at a point are 129°. Find the Intersection angle.

Draw sketch -- Fig.49

Included Angle $= 240^\circ - 129^\circ = 111^\circ$

Intersection Angle = External angle = $180^{\circ} -- 111^{\circ} = 69^{\circ}$

2. What is the Intersection angle, if the bearings of the two straights AB and BC are 120° and 175° respectively?

Draw Sketch (Fig.50)

Intersection angle $I = A_1BC = 175^{\circ} -- 120^{\circ} = 55^{\circ}$

3. The Centre line of a road is to be deflected through an angle of 100° to the right from a point whose chainage is 6229.18 feet by a circular curve of 100 feet radius. Tabulate the offsets required and explain how you would lay out the curve on ground.

Intersection Angle $I = 100^{\circ}$

Tangent Length $T = 100 \times \tan \frac{100^{\circ}}{2} = 100 \times 1.1918 = 119.18$ feet.

Chainage of $T_1 = 6229.18 -- 119.18 = 6110$ feet.

Length of Curve = $0.01745 \times 100 \times 100 = 174.5$ feet.

Therefore Chainage of $T_2 = 6110 + 174.5 = 6284.5$ feet.

Since radius is less than 100 feet, 25 feet standard chord may be used.

Initial subchord $C_1 = 6125 -- 6110 = 15$ feet

and final sub-chord = $6284.5 -- 6275 = 9.5$ feet

Then Offset for 1st Chord C_1 is $O_1 = \frac{C_1(C_1+Co)}{2R}$

$$= \frac{15(15+0)}{2 \times 100} = 1.25 \text{ feet}$$

$$O_2 = \frac{C(C_2 + C_1)}{2R} = \frac{25(25+15)}{2 \times 100} = 5.0 \text{ feet}$$

$$O_3 = \frac{C_3(C_3+C_2)}{2R} = \frac{25(25+25)}{2 \times 100} = 6.25 \text{ feet}$$

$$O_4 = \frac{25(25+25)}{2 \times 100} = 6.25 \text{ feet}$$

Offset for Final Sub-chord $O_1 = \frac{9.5(9.5+25)}{2 \times 100} = 1.64$ feet.

The Values may be tabulated as follows:-

Peg No.	Chord Length feet	Offset feet	Offset feet	Remarks
T_1	0	6110	0.0	Initial Tangent Point.
a	15	25	1.125	First Peg on curve
b	25	50	5.0	
c	25	75	6.25	
d	25	6200	6.25	
e	25	25	6.25	
f	25	50	6.25	
g	25	75	6.25	Last Peg on curve.
T_2	9.5	6284.5	1.64	Final Tangent Point.

4. To set out the curve, the following procedure may be adopted:-

(1) Along the tangent (AX Fig.50-a), mark $T_1 a_1 = C_1$

With the zero of the tape at T_1 as centre and a reading equal to $T_1 a_1 = C_1$, swing the chord-length inwards until the offset $A_1 a = O_1$ and fix a. Alternatively, with the zero of a linen tape at T_1 and alength equal to $(C_1 + O_1)$ at mark a_1, hold an arrow at length C_1 on tape and stretch the tape taught and fix point a on curve.

(2) By means of ranging rods at T_1 and a, produce $T_1 a$ to b_1 such that $ab_1 = C$. With a as centre and radius equal to C, swing the chord inward until the offset $b_1 b = O_2$ and fix peg b.

(3) Produce chord ab to c_1 such that B bc - C and repeat till the end of the curve is reached, with the last chord produced to a length equal to C_1 and offset equal to O_1 which should coincide with T_2.

If the initial sub-chord is too small for an accurate prolongation, first fix position of a as above. Then consider the curve extended back-wards (as shown in Fig.50-b) and swing a chord $T_1 P_1 = C - C_1$ until the offset $P_1 P = \frac{(C = C_1)^2}{2R}$

and fix point p, so that pa = Standard Chord length C. Now produce pa to b_1 so that ab_1 = C and swing the chord until the offset $b_1b = \frac{C(C+C)}{2R}$ II or II $\frac{C^2}{R}$ as for general chord and fix point b, Proceed as before.

Example 4:-- Furnish offset distances for setting out a 5° curve, 70 m (350') long by chords and offset outside the curve, the chord lengths for the first three offsets being 20 m (100') and for the last one 10m (50').

$R = \frac{1146}{5} = 229$ m $\qquad$ $R = \frac{5730}{5} = 1146$ feet

$O_1 = \frac{20(20+0)}{2 \times 229} = 0.47$ m $\qquad$ $O_1 = \frac{100(100+0)}{2 \times 1146} = 4.36$ feet

$O_2 = \frac{20(20+20)}{2 \times 229} = 0.95$ m $\qquad$ $O_2 = \frac{100(100+100)}{2 \times 1146} = 8.73$ feet

$O_3 = \frac{20(20+20)}{2 \times 229} = 0.95$ m $\qquad$ $O_3 = \frac{100(100+100)}{2 \times 1146} = 8.73$ feet

$O_4 = \frac{10(10+20)}{2 \times 229} = 0.66$ m $\qquad$ $O_4 = \frac{50(50+100)}{2 \times 1146} = 3.27$ feet.

15. To join two straight lines by a Parabolic curve:- This method is very useful when the tangents are unequal.

(1) Fix Tangent Points at convenient points, T_1 and T_2 on the straights, See Fig.51.

(2) Divide both tangents into the same number of equal parts and put ranging rods at these points e.g., in Fig. 51 the tangents are divided into four parts:-

$T_1C = CB = BA = AX$,

and $XD = DF = EF = FT_2$

(3) points on the curve are obtained by the intersection of

T_1D with CE,

CF with BF,

and BF with AT_2

SECTION:6: PRINCIPLES OF ROAD CONSTRUCTION

34. Organisation of Laboratory Labour

1. The speed and quality of the work will depend upon the way in which the available labour is handled. Camp sites for coolies must be located near to the work and a good water supply provided. Otherwise a lot of time and energy will be wasted the workmen getting to the site of work and back home.

2. Wherever possible, the work should be done by contract or on a piece-work basis, rather than by employing labour on daily wages, since less supervision will be needed, and is therefore more economical.

3. The work should be divided so that not more than 15 to 20 men may work in a gang, each under a headman, or each section may be worked on a petty contract basis.

4. Definite sections of road should be completed before a gang is allowed to move to another piece of work; otherwise, the men will try to leave the moredifficult parts, and, after being paid for the easy work, will run away. The remaining portions of the work will then have to be paid for at special high rates and also measurements will be difficult.

35. Tools used

1. When work is to be done departmentally by employing men on daily wages, it will be necessary to supply tools. Delays are frequently caused by insufficient number of tools being available. Sufficient number of each tool should be provided. So that one third of the total number can always be under repairs.

2. The spade or pharah, Fig.52, is good for digging in ordinary soft earth.

3. The pick-axe, Fig.53, is generally used for breaking ground, stiff soil, disintegrated soft rocks and to dig boulded. They are made of iron to which steel points are welded, one being pointed while the other is chisel-shaped. The usual defect is a want of sufficient strength in the socket where hand is fixed, which should be tested.

4. The Showel, Fig.54:- The heart-shapped showel is preferred to the straight edged one. Long handles are sometimes provided but the short crooked handle shown is stronger and cheaper.

5. A good bamboo basket holding 30 cubic decimetres ($0.0m^3$ or one full cubic foot) of earth would cost but very little more than an inferior one, but is more economical, and lastes double the time.

6. Good iron pans last longer than inferior varieties.

7. Wheel barrows may be used for moving materials in large scale works. It consists of two long arms, Fig.55, with two cross-pieces mortised in and secured by iron straps. At one end the arms are placed at convenient distance apart for a man's hands and carry two legs for resting the barrow on groupd; they close up at the other end to support the axle of a wheel in front. To the top of the frame is fixed a deep metal tray with a capacity of $0.06m^3$ (2cft.).

8. The Crow-bars are used for levering large stones or tree stumps. In rocky ground it is better to provide each gang with two cros-bars, otherwise they will often break other tools.

9. Strong String or cable for aligning and setting out curves and embankments, etc.

10. Saws, axes, bill-hooks, sickles, etc., for clearing jungl growth and felling and uprooting of trees.

11. Where blasting of rock is to be done, the boring tools such as jumpers, drill-bars and sledge hammer and explosives like gunpowder or dynamite or plastic explosive, and detonators, tamping rods, scrapers, safety fuse, safety matches and red flags, etc. Should be provided. Where electrical fuse is used, sufficient length of wiring, testing boxes and exploder boxes should be obtained.

Since here rock is to be blown away to clear the path, great blast is the one employed, and all precautions must be taken for the safety of lives. The minimum safety distance for the blasting will be 100 metres (100 yards) all round.

In the case of a misfire no one will be allowed to enter the danger area till 10 minutes after the attempt to fire if electric circuit has been used, or 30 minutes if safety fuse is used. No attempt should be made to remove misfired charge; it should be detonated by firing another charge adjacent to it.

36. Clearing the Road way.

1. The first step is to clear the 30 cm (1') trace and replace the missing or broken pegs. Contractor's workmen should be instructed that no pegs should be removed during the progress of work and ground for 30 cm (one foot) around peg should be left untouched until earthwork is completed and measured for payment.

2. Jungle-clearing should be completed well in advance of starting the earth-work, since it is often possible to straighten out some unnecessary bends and improve the alignment. All trees and bamboo clumps, within the actual width of road should be uprooted during the clearing, except on steep hill sides where stumps are likely to come out when earth is excavated. It is better that the rate for uprooting should include removal to a distance of 10m (33 feet) from the road-side.

3. It is generally not economical to blast the roots except in very hard and rocky ground, Large stumps can often be split by iron wedges, and old and dry roots can be destroyed by burning.

In level country after all the jungle growth has been

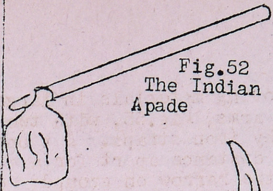


Fig.52 The Indian Apade

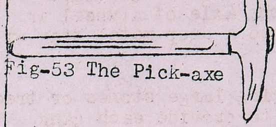
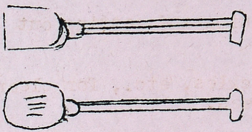


Fig-53 The Pick-axe



Eig.54 Showels.

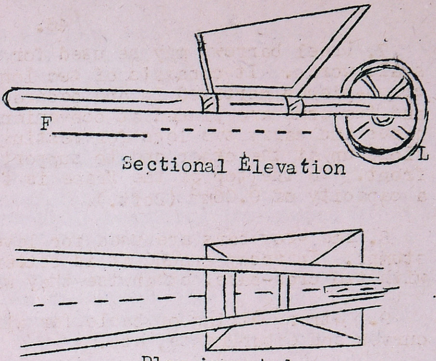

F
L
Sectional Elevation
Plan-inverted

Fig.55 The Wheel barrow

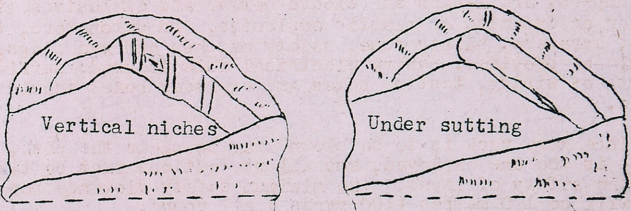

Vertical niches
Under sutting

Fig.56 Earthwork excavation

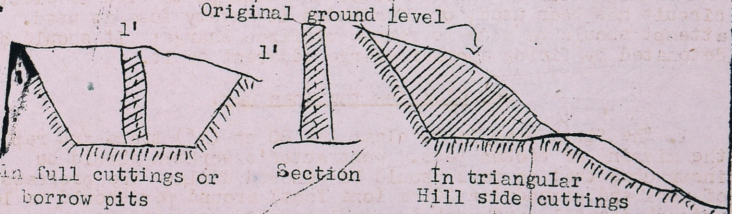

Original ground level
1'
1'
In full cuttings or borrow pits
Section
In triangular Hill side cuttings

Fig.57 ~~Dead men or~~ witness pillars

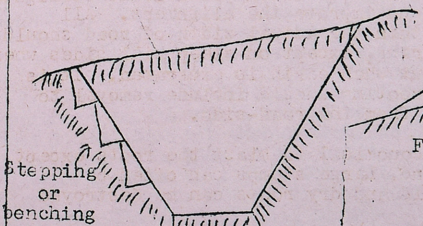

Stepping or benching

Fig.58 Removal of earth from deep & long cuttings.

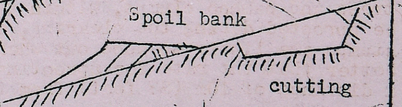

Spoil bank
cutting

Fig.59 Spoil banks.

cleared, the top vegetation is dug out, and uneven portions levelled by filling up all natural hollows or holes from which stumps or boulders are removed, and well rammed. Two side drains are excavated and the earth thrown on to the middle of the road to form the necessary camber.

37. Formation of Cuttings

1. The top soil or vegetative mould is stripped to a depth of about 20 cm (8') and preserved for resoiling the slopes of earthwork for stabilizing the new slopes.

2. A cutting on a hill-side is usually begun by cutting a fairly vertical face at right angles to the centre line. From this face, vertical niches are cut at about 1.5 m (4') intervals as shown in Fig.56-a and then the earth between the niches are levered out with crow-bars.

Another method is to under cut the face with pick-axes near to the bottom of the cutting (Fig.56-b) and lever out the mass of earth with crow-bars from the top of the cutting.

3. Just enough men should be employed against a cutting face, so that workmen may not get into one another's way.

4. The order in which portions are taken out from a cutting is immaterial. In fairly stable soil, the central rectangular portion is generally first cut out as it is then possible to engage more men along the side-slopes to quicken the work. Correct side-slopes may be formed with the help of a slope template. Niches are first cut at 10 to 15 metre (30 to 50 feet) intervals to the correft slope and then the ground between them evened out.

5. In all cuttings conical pillars of earth called Dead-men or witness pillars must be left at marked places at short intervals. Fig.57, until earthwork is completed and measured. These not only help measurement of areas of earthwork, but also help preserve the centre-line. The original grass growing on them continues to grow and prevents any dispute regarding depth of cutting, but care should be taken to see that contractors may not remove the top soil, and a few centimetres (inches) to the height of the pillar and replace top soil, dressing the sides to make them appear as natural soil.

6. In a short length of deep cutting, the excavated earth can be brought out in baskets or barrows at one end of the cutting. In long cuttings of shallow depth upto 2 metres (t or 6 feet) the earth can be lifted up in baskets and removed by other men. Removal of excavated earth from deep and long cuttings may be arranged by stages, by cutting the side-slopes in steps of about 1.5 m (5') in height Fig.58.

7. The excavated earth, when not required for forming an embankment in the road, should be formed into neat, regular spoil banks, and not thrown haphazardly. These must be formed on the down-hill side of the cutting, Fig.59, with their toes at least 1 metre (3') away from the edge of cutting, with a uniform height throughoutm but of varying widths depending upon the amount of earth. These should not be made condinuous, but gaps of about 3 metres (10'0 should be left after every 30 metres (100') of bank

for natural drainage.

38. Formation of Embankment

1. While forming road embankments, care should be taken that sufficient waterway is provided for all intercepted streams and natural drainage. Frequent small culverts are better than a few large ones.

2. Barrow Pits:-- When earth required for forming the embankment cannot be economically obtained from a nearby cutting, it will be necessary to excavate special pits called borrow pits. These should never be located nearer than 2 metres (6 feet) from the toe of the bank, and should not be deeper than 1 metre (3 feet) generally. They should not form long continuous channels, but may be separate pits about 50 m (100') in length with intervals of 5 metres (10( ) between them. Wherever possible, the borrow pits should be connected to the nearest natural water-course, so that water may not stagnate in them.

On side long ground, borrow pits may be provided on the uphill-side so that they may act as catch-water drains. The positions of borrow pits and witness-pillars in each should be marked out before starting excavation. These witness-pillars should not be removed till measurements are taken, but they must be removed at the time of measuring for payment. No pit without a witness pillar should ever be measure for payment.

3. The best materials for road embankments are those having the greater frictional stability and which settle least, such as shingle gravel and clean sand,. Heavy clay or black cotton soil should be avoided, where possible.

4. The best method of raising an embankment is to lay the earth in a succession of thin layers of about 30 to 50 cm (1 or 2ft.) thickness watering and remming or rolling each layer before the next is laid. The laying is commenced at the toes of the bank so that the layers slightly dip down towards the centre and prevent the bank from slipping out as shown in Fig.60-a.

5. When a bank is to be made on a hill side the slopping ground is cut in steps or benches dipping down at right angles to the side slope of the bank (Fig.60-b) and earth is consolidated in layers. This assists in binding the new soil with the original This assists ground, and prevents the bank from slipping down the hill-side.

6. Care should be taken to see that all clodes of earth are broken up before the earth is loaded into the basket or barrow, and again immediately after it is deposited in the bank, otherwise the bank will settle uneyenly, and later it will be full of hollows. Donkeys are frequently used to carry the earth from the borrow pit to the bank, and this will help in breaking clods and consolidating the layers.

Bullock-drawn 2 tonnes (ton) stone road rollers or 6 to 8 tonne (ton) steam road rollers may be used for proper consolidation, but the layers of earth laid should not exceed 30 to 50 cm (1 or 2 ft.) otherwise any amount of rolling will not break up all the clodes.

7. A new embankment should be allowed to weather for at least one monsoon before laying soling and metal. Just before the monsoon, the top surface of the bank should be divided into shallow compartments by small earthern bunds about 10 cm (3 inches high) so that water may collect in them and soak into the bank.

8. Earthwork in embankment is calculated from the dimensions of the borrow pits from which earth is obtained and not from the measurements of the bank. For, the volume of earth, on excavation and exposure, increases, and as time passes, the earthwork again settles down.

9. Allowance for settlements-- All made-up earth is liable to settle down, some more and some less. The actual amount of settlement depends upon the nature of the soil, height of bank the method of forming it, and the amount of consolidation it receives. The dotted lines in Fig.10 show the original section of an embankment and the continuous lines the from it takes after settlement.

The following allowances may be made for shrinkage of earthwork, unless the exact amount is determined by experimental data:-

In compact earth or gravel	10 cm per m	(1½"/foot) of height.
Ordinary soil	15 cm "	(2"/foot) "
Heavy clays or black cotton soil	20 cm "	(3"/foot) "

The sides of an embankment aalso shrink and are eroded, and hence the bank usually made slightly wider than the finished formation width required

39. Masonry Structures in Roads.

1. The important bridges, over 6 metres (20 feet) span, are built up simultaneously with the commencement of the road, by differént agencies. But small works like irish bridges, culverts, retaining and breast walls, etc, are carried out by the same agency as the roadwork, as the work progresses.

2. Approaches to the bridges and culverts must be constructed early to allow for settlement, though the necessary top-dressing and camber or super elevation are added on later.

40. The Sub-grade

1. The object is to prevent stagnation of water, as it makes the road-bed soft and liable to be cut up under the traffic. The necessary camber should be provided by raising the centre of road above the edges by adding earth excavated from side drains or borrow pits.

2. Where soil is heavy clay or black cotton soil, sub-soil drainage should be provided as required.

1. Most Forest roads are earth roads with no special surfaceing, as they are usually fair-weather roads. The road-surface can, however, be considerably improved by sand or gravel dressing.

2. Where the surface soil is heavy clay a top dressing of sand will create a bettersurface by lessening, its stiffness. The sand gradually gets mixed up with the clay, and more sand should be spread each year until the road becomes satisfactory.

3. Where the soil is very loose and sandy, the road surface can be improved by spreading clay over it. Another remedy in the case of forest roads is to cut tall non-fodder grass growing nearby and spread it across the road in a thin layer; the drains should be kept free from grass, and a gap of 1 metre (3') should be left after every 30 m (100') or carpetting with grass, to limit damage due to accidental fires. In course of time grass will bind the surface sand particles together and a better road will result. For light traffic and in garden paths or house compound P.B.S. (Pre-fabricated Bituminous surface) sheets -- rolls of jute joined by heating a mixture of diesel oil and petrol spread at the junctions.

42. Laterite Roads

1. Laterite is a form of clay-stone containing iron oxide, which gives it the reddish yellow tinge. For roadwork, it should be hard, dark in colour, heavy and compact in texture, and must not contain much pure clay; the mottled appearance and streaked colours should be fairly evenly distributed. It is quite soft for excavating with a pick-axe, and hardens on exposure; it should, therefore, be broken to required sizes and stacked in small heaps for at least 6 months before using in the road.

2. Bigger laterite stones, 10 to 15 cm (4" to 6") in size, are laid evenly to camber, handpacked and rolled. Stones of 5 to 8 cm (2" to 3") gauging are then laid to a thickness of 10 to 15 cm (4" to 6"), packed by hand, and rolled thoroughly to consolidation. A thin dressing of sand-topping is often added to provide a sealing coat.

43. Corduroy or Plank Roads

1. Timber roads are at best only temporary expedients, as timber will deteriorate in course of time, and they are resorted to in very soft marshy ground or swampy areas.

2. The side drains are first excavated deep enough to drain the formation and the excavated earth thrown on to the centre of the roadway to give the camber. Then transverse bearers, Fig.61 which are formed of fascines. (10 to 20 cm diametre bundles of long brushwood) in forest work are bedded across the road-width at 1m (3') intervals into and level with the surface of subgrade. Stringers or runners are then laid over these bearers.

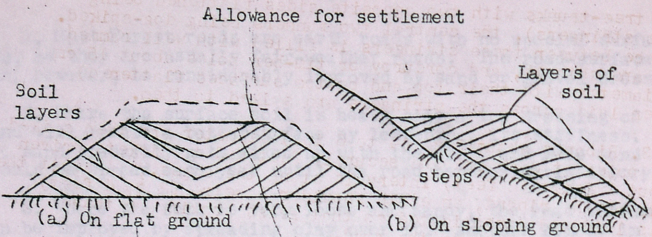

Allowance for settlement
Soil layers
Layers of soil
steps
(a) On flat ground
(b) On sloping ground

Fig. 60 Formation of Embankments

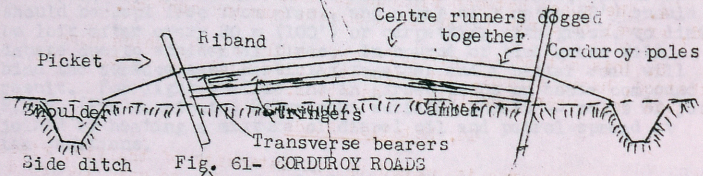

Centre runners dogged together
Riband
Corduroy poles
Picket
Shoulder
Stringers
Camber
Transverse bearers
Side ditch

Fig. 61- CORDUROY ROADS

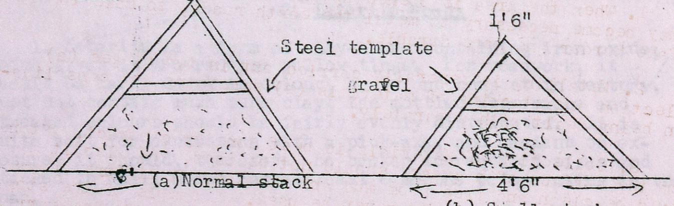

1'6"
Steel template
gravel
6'
(a)Normal stack
4'6"
(b) Small stack

Fig. 62 Stacking of metal, sand and gravel

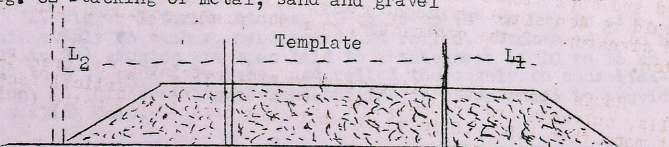

Template
L2
L1

Fig.63 Measurement of stacks.

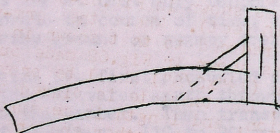


Fig.64 THE CAMBER TEMPLATE

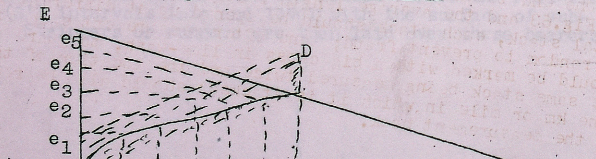

E
e5
e4
e3
e2
e1
D
A
c1
c2
c3
c4
c5
C
B

Fig. Construction of a road camber template (large tree-trunks with two opposite sides flattened being used as stringers), the central two runners being dog-spiked. The space between these stringers is filled with well rammed soling and shingle, and corduroy or timber poles about 15 cm (6") diameter with their top and bottom surfaces flattened) are then laid across the stringers and spiked to them.

3. Ribands about15 cm (4 to 6 in.) diameter are then spiked to the poles at each end and securely fastened to pickets driven at about 1 metre (3 feet) intervals along the edges., Against the outside of the riband, an earth shoulder 1 metre (3 to 4 feet) wide is laid and consolidated so that grass growing on these shoulders may help secure the road.

4. The space between ribands is then filled with brushwood, sand, gravel or earth to obtain a smooth running surface.

5. This method has given fairly stable roads, which have withstood, heavy storms, but evidently they would be costly, and are used only where absulutely essential.

44. Metalled Roads

1. When the area is opened up and intensity of traffic, rises, it may become necessary to metal the earth roads, to make the road surface harder and more durable.

2. Metalling is generally carried out in two stages (a) collection and stacking of materials (b) spreading and consolidation being dealt with separately.

3. Collection of Materials is best done by contract. Stone from the surface of a quarry should not be used, and also it should be clean and free from mud and rubbish. A mixture of hard and soft stones should never be used. A sample of the stones should be deposited at headquarters, with the name of the quarry and signature of the contractor, and the supply compared with it often.

Rough stones for soling, revetments, retaining and breast-walls, culverts and bridges, etc. are stacked with vertical faces, not more than 1.5 m (5 feet) in whdth not more than 1 metre (3 feet) in height.

Broken stones, gravel and sand are stacked in marked positions with a cross section as shown in Fig.62-a and of lengths in multiples of 5 metres (10 feet). Where the berm-width is limited, the cross-section may be reduced to that shown in Fig.62-b . Templates of these dimensions as shown in Fig.62 made out of timber or mild steel flat 40 x 10 mm (1½"x3/8") shall be provided by the contractor. For measuring, the template is placed on the stack to check the cross-section, and length is measured from the top at one end to the bottom at the other end and vice versa, as shown in Fig.63 and the average length recorded. While measuring a metal stack, each stack should be opened up at different places at random to prevent fraud; and after measurement each stack should be marked with a big cross in lime-wash, to guard against the same stack being measured twice and the location of the stack (the km or mile in which it is stacked) should also be recorded in the measurement book.

4. Metalling, Fig.6:- On the prepared formation a uniform layer 10 to 25 cm. (4 to 10 inches thick) of soling stones is carefully packed and consolidated, they are ~~a~~ set with their lengths across the road and their broad ends down, and are arranged to break joints as much as possible. All projecting corners are then beaten down with a hammer and the interstices filled with smaller stones and chipbines to get an even, compact foundation, which is rolled to consolidation.

On this laid a 10 cm.(4") layer of 5 to 6 cm.(2 to 2½") broken stones(metal)hand packed and rolled to consolidation. The rolling should commence at the edges of the road and proceed towards the centre so as to push up the metal towards centre-line of the road to preserve the camber.

Then a 10 to 15 mm.(½") topping of gravel, murum or nala ~~AN~~ sand or other blinding materials should be spread on the wearing course, flooded with water so that it may form slush and work well into the interestices of the metal. A thin layer 5 to 10 mm.(3/8 in)of sand or fine bajri is then spread on it to prevent the slush sticking to the roller, and the rolling is continued until a loaded countrycart(with steel rimmed wheels)does not produce any mark on it.

In Forest roads, I metre (3 feet)wide stone road-roller drawn by bullocks is the one generally used. Steam road rollers, when used, should not exceed 8 to 10 tones(tons)in weight.

The shoulders should be raised simultaneously with the roadway to provide the necessary side support.

Every road should be a water-shed and not a water-course, and hence, the tendency to dig up the ground to lay the foundation and wearing courses should be guarded against.

45. The Camber Template

1. A template should be used to ensure that the designed chamber is properly provided for the road during construction. Fig.64 gives a good form of template and Fig.65 illustrates the method of its construction.

2. On the hard smooth surface of the template floor, say a pavement or verandah floor, mark a straight line AB equal to the width of the roadway. Biset AB at C Fig.65 and erect CD perpendicular to AB and equal to the required camber. At ~~A~~ A erect the perpendicular to AE equal to twice CD. Divide AE and AC each into the same number of equal parts, say 6, at e_1, e_2 etc. and c_1, c_2 etc. respectively. Join B to points e_1, e_2 etc. to meet the perpendiculars to AB at c_1, c_2 etc. in o_1, ~~A~~ o_2, o_3, etc. These points of intersection o_1, o_2, o_3 ....etc. are then on the required curve of camber. Join AD, and measure~~d~~ the perpendicular distances of these points on the curve from AD, as shown by chain-dotted line, which give the required curve to which the plank is to be cut.

3. Such a template covers half the width of the metalled portion of the road, and is used alternately on each side. It is fitted with an arm and a plumb bob, as shown in Fig. 64 and is formed of 2 cm (3/4 inch) plank, the lower edge being cut to the required curvature).

SECTION 7: MAINTENANCE OF ROADS

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46. General

1. Maintenance of a road consists in the continuous preservation of its surface in a good state by means of routine repair work carried out by gangs of permanent staff. All roads require constant attention, and if small repairs are carried out at once, more expensive repairs will be avoided later. A large proportion of the money spent on repairs to forest roads can be saved, if proper attention is paid to the maintenance of the road drains; more damage is done to the earth-roads by the scouring and erosion of the surface by the water than is caused by traffic. The drains must be repaired at the beginning of the rains and should be kept continually in repair throughout the rainy season.

2. The efficiency of road maintenance is judged by the condition of its worst section, and one should acquaint himself with the whole length of the road by periodical inspection in order to find out the needs of repairs. The best time to inspect a road is during, or immediately after a heavy rain. The repairs to the road should be carried out at the end of the rainly season while the ground is still soft and in a condition to consolidate.

3. One has to prepare an estimate each year for the repairs required to roads and paths in his charge. In detailing the repairs, reference should be made to the correct kilometer in which it is required, as also the length and nature of repairs necessary, and the estimated cost of repairs. To assist him in the proper maintenance of the roads in his charge, following records should be maintained up-to-date.

(i) A large scale map of all the roads;
(ii) Plans and sections of the road-surfaces and of all important masonry work;
(iii) A statement, km by km (mile by mile) of the correct formation width, average, maximum and minimum;
(iv) Registers of all land occupied by the road, buildings and quarries;
(v) Road charts showing annual progress of surfacing, km by km (mile by mile);

(vi) Schedules of the rate cost of preparing materials at the quarries, and the cost of transporting them;
(vii) Annual inspection reports on the roads, buildings, bridges and cross drainage works;
(viii) Annual reports of abnormal floods.

4. The main principles to be followed in maintaining a metalled road are:-

(a) Frequent removal of mud and dust, which, if left, aids in the deterioration of the surface by grinding action;

(b) Prompt repair by renewing lost material
(c) Efficient drainage;
(d) Complete renewal of the waterproof covering before the surface has worn through.

47. Wear of Roads

1. The wear of a road surface may be due to

(a) Surface wear due to traffice and weather, and
(b) interior wear due to weather, intensified by traffice

Provided proper drainage for the foundation is maintained, the provision of a waterproof surface will reduce the effects of weather to a minimum.

2. The life of a road can be prolonged by using wheels of large diameter tyres of width suitable for the axle loads, pneumatic tyres, proper springs, and reduction of speeds on curves.

48. Surface maintenance

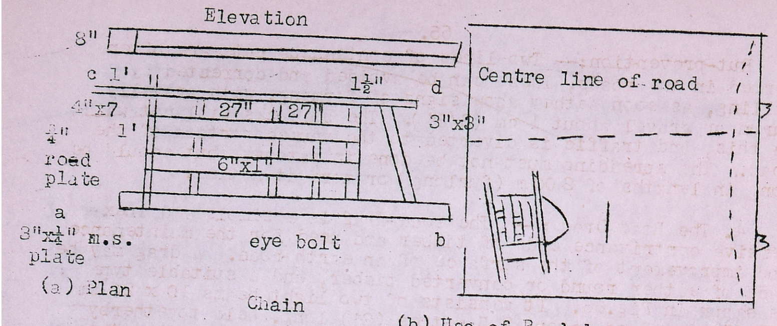
1. The principal duties of each man in charge of a section of the road will be to keep it free from loose stones and mud, to attend to the drainages and clear out fullies, and to keep the foot-paths clean and smooth.

2. The periodic clearing of a road-surface will effect great economy by preserving its life, the more frequently mud and dust are removed, the slower will be the disintegration of the surface. In dry weather, siliceous or flinty stones tend to work loose and a certain amount of the binding material works its way to the surface; this should not at all be removed, and judicious watering is necessary to keep this material down.

Mud must be in a sufficiently fluid condition to be capable of easy removal; otherwise in the attempt to clean the surfact the crapers are liable to damage the surfact, the scrapers are liable to damage the surfact by loosening the stones.

3. Patching, ruts and hollows:-- Patching is a method of repairing irregular wear of road surface by attending to the bad spots as they appear, thereby delaying the ultimate necessity of resurfacing of the road. The work out place should be cut to the full depth of the metal, the hole so cut being rectangular in shape with the edges kept vertical. The road metal(or gravel in the case of an earth-road)is then laid in the holes, the surface being brought up to slightly above the road. It is then watered and consolidated with heavy iron rammers to the same degree of hardness as a new coat of metal; finally a top dressing of fine stuff is put on and rammed in, until the finished surface of the new patch lies perfectly even with the surface of the road.

The best time to do patching is at the beginning of the monsoon, as the water will then stand in the holes and show them up, and also water will be more easily available then for consolidation. However, large holes must be patched up immediately they are noticed, as a stich-in-time policy is the best in this connection.


Elevation
8"
c 1'
1½"
d
4"x7
27"
27"
1'
¼"
road
plate
6"x1"
3"x3"
a
3"x¼" m.s.
plate
eye bolt
b
Chain
Centre line of road
3
3

(a) Plan

(b) Use of Road drag

Fig: 66 THE ROAD DRAG

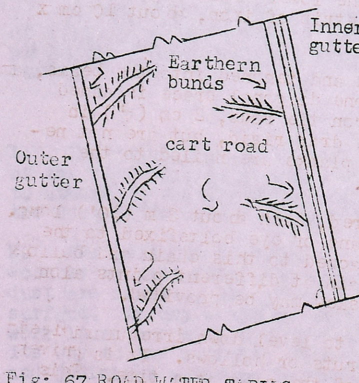

Inner
gutter
Earthern
bunds
cart road
Outer
gutter

Fig: 67 ROAD WATER TABLES.

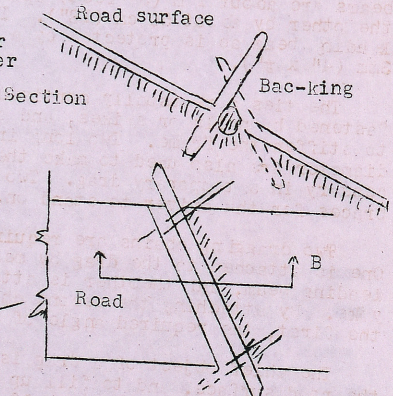

Road surface
Section
Bac-king
B
Road

Fig: 68 POLE DRAINS.

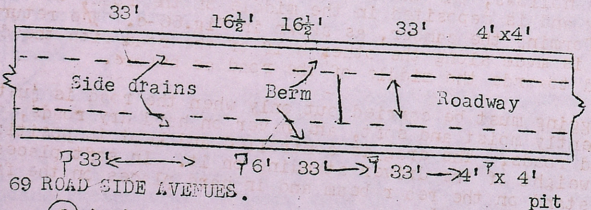
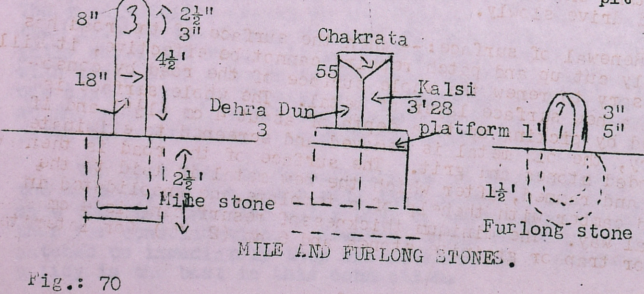

33'
16½'
16½'
33'
4'x4'
Side drains
Berm
Roadway
33'
6'
33
33'
4' x 4'
pit

Fig. 69 ROAD SIDE AVENUES.


8"
2½"
3"
4½'
18"
Chakrata
55
Kalsi
3'28
Dehra Dun
3
platform 1'
3"
5"
2½'
Mile stone
1½'
Furlong stone

MILE AND FURLONG STONES.

Fig.: 70

Rut-prevention:-- Two lines of continuous ruts are often formed in the roads, These can be avoided and corrected by filling, as soon as they show signs of forming, with gravelly murum or gravel about 1 cm (3/8"). The bullocks will not walk on this, and traffic is diverted to the unused portion of the road.. The spreading must not be done in patches, but should be done in lengths of 200 m (furlong) or more at a time.

4. The Road Drag :-- The road-drag is a simple and inexpensive contrivance made of timber and used for the maintenance and improvement of the surface of an earth-road. A drag may be made of either round or converted timber, and a suitable type is shown in Fig.66. It consists of two light beams 10 x 20 cm (4"x8") ab and cd, about 2.5 metres (8') long, held together by four ties of timber scantling 8 x 8 cm (3" x 3"), so that the beams are about 1 m (3' feet) apart, with one end overlapping the other by about 50 cm (18"). The lower front edge of the leading beam ab is protected by a strip of iron, about 10 cm x 3mm (4" x $\frac{1}{8}$").

The ties are usually mortised and tenoned into the beams, and fastened by nails or spikes, and one diagonal brace is added to stiffen the frame. Two long iron tie rods, 2 cm ($\frac{3}{4}$") in diameter are also used to make the drag rigid, but are not necessary in a temporary drag. Two planks are nailed to the braces for the driver to stand on.

Two dragging chains are required, each about 3 m (10') long. One is attached to the drag by means of eye bolts fixed to the leading beam, and the other is attached to this chain and bullock yoke. By attaching the second chain at different points along the first, the required angle of skew may be provided.

The chief object of a drag is to level down irregularities in the road surface, and to fill up ruts or hollows. It is driven at a slight angle, down one-half of the road at a time. This causes some of the loose mud and surface soil to be filled into the hollows, and the remainder passes along the front of the drag and is deposited in the middle of the road, thus assisting in forming the camber, as shown in Fig.66-c. The return journey is made along the other half of the road with the drag inclined towards the middle of the road as before.

Dragging must be carried out only when the road is just sufficiently moist and soft, and never on hard dry roads, or metalled roads, The drag is controlled and kept in position., by the weight of the driver standing on it. In soft places he should stand on the rear beam and in hard places on the front beam, and drive slowly.

5. Renewal of surface:-- When the surface of the road has been badly cut up and patch repairs cannot be effective, it will be necessary to renew the whole surface of the road by consolidating a new surface layer of metal. The whole surface is sacrified by picking up to a depth of about 4 cm ($1\frac{1}{2}$") and if necessary, the old metal is removed and screened to eliminate the rounded stones and grit. The surface of the road is then watered and rammed, after which the new metal is laid to the required camber with the help of a template, and consolidated in the usual way. The minimum thickness of resurfacing is 4 cm ($1\frac{1}{2}$") for trap or grainite stones and 6 cm ($2\frac{1}{2}$") for laterite stones.

6. The Repainting of km (mile and furlong) stones, boundary pillars, sign posts, etc.are generally done by petty contractor annually, immeidately after the rainy season.

49. Improvement of Existing roads.

1. In impoving metalled roads in poor condition, the following procedure may be adopted:-

(i) Establish logitudinal side-drains and cut wide gaps through the banks of earth, mud and rubbish, which may be bound on either side of the road. In very bad places, it may be necessary to add sub-soil drainage.

(ii) Sweep mud and water off the road-surface, using brooms throwing all solid mud, debris or spoil clear of the drains on the far side.

(iii) Repair the worst ruts and holes, by cutting them out square, and filling in with metal well rammed.

(iv) Restore the shape and camber to the surface, if sufficient metal is available. It is necesary to scarify the old surface with picks, before spreading the new metal for consolidation.

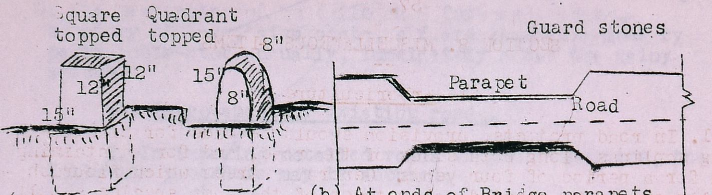
(v) Earth shoulders at the sides of the roadway should not be interfered with unless they can be replaced with metal.

50. Road water Tables and Pole Drains.

1. Road water Tables are small oblique cross bands placed during the monsoon on steep hillside roads, to divert water into the side gutters. They are made of clay about 8 to 10 cm(3 to 4 inches) high and about 10 metres (33') apart on a 1 in 20 gradient, and farther apart on flatter gradients. Only on roads impassable during the monsoon should these be placed all across the road; on other roads they may project about 2 metres (6 feet) only from the gutter, and the road camber, if propertly maintained, should be the rest;- Fig. 67.

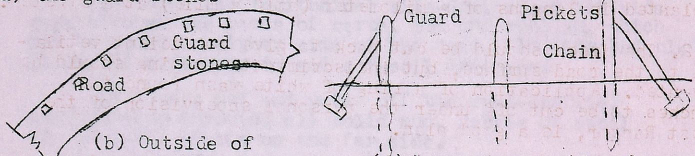
2. Pole-Drains may be used as an alternatime to the water tables, but they can be used only on earth-roads. They consist of poles placed obliquely across the road to prevent the rain water from running along the road-surface oon account of the steep gradients. They may be placed at intervals of half-chain length on steep gradiants, and farther apart on flatter grades. On bridle paths, they may be left in place all the year round, but on cart-roads, they should be removed just after the monsoons and replaced before the next monsoons.

Poles about 10 to 15 cm (4 to 6 inches) in diameter are embedded in a shallow trench, so that half the pole is covered. The trench is dug diagonally across the road, as shown in Fig. 68, so that it slants outwards in the direction of the slope. The pole is fastened down at each end by two strong pegs, the inner end of the pole may be inserted into the hill-side, which will hold it better than the pegs along. The earth from the small trench should be used as a backing on the lower side of the pole.


Square topped
Quadrant topped
12"
12"
15"
15"
8"
8"
Guard stones
Parapet
Road

(a) the guard stones

(b) At ends of Bridge parapets


Guard stones
Road
Guard
Pickets
Chain

(b) Outside of curves

(d) Down-stream side of causeways

Fig: 71 GUARD STONES

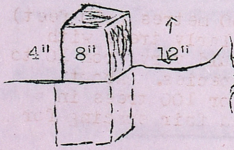


Fig.72 BOUNDARY STONES

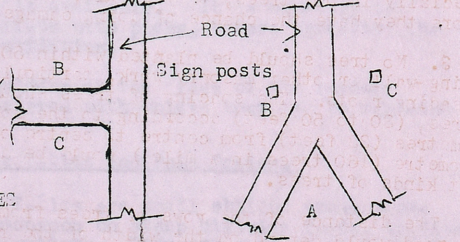

Road
Sign posts
B
C
B
C
A

Fig: 73-b POSITIONS OF SIGN BOARDS AT ROAD JUNCTIONS AT 'A' PREFERED

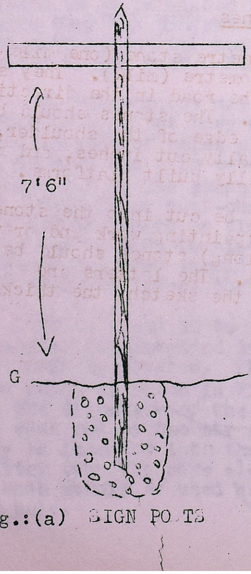


Fig.:(a) SIGN POSTS

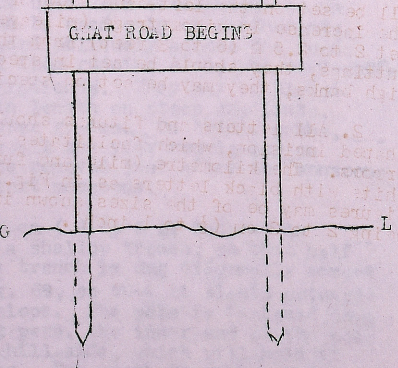

GHAT ROAD BEGINS
G
L

Fig. 74 NOTICE BOARDS

SECTION 8. MISCELLANEOUS ITEMS

--

51. Arboriculture

1. In road projects, provision should be made for planting young saplings along both sides of the road, and for maintaining them for a period of four years. Generally trees which flourish locally should be planted, also trees of the same species should be planted in lengths of a milometer (half a mile) at a stretch.

2. The trees should be cut back to give sufficient vetila - tion to the road surface, but indiscriminate lopping should be prevented. Application of a ring of white-wash round the branches to be cut off under the personal supervision of the Forest Ranger, is a good plan.

The cutting back of trees looks bad at first, but after a few years, a higher avenue is produced which adds greatly to the effect. Heavy horizontal branchesof banyan and other trees are dangerous, as they sometimes crash of their own weight, especially in old trees; they should, therefore, be cut back before they have the chance of doing damage.

3. No tree should be planted within 50 metres (150 feet) of a wing-wall or other masonry work, particularly trees with spreading roots. The spacing of trees should vary from 10 to 15 metres, (30 to 50 feet) according to the species. About 10 metres (33 feet) from centre to centre or 100 trees in a kilometre (160 trees in a mile) would be a fair spacing for most kinds of trees.

The distance of the rows of trees from the centre-line of the road would depend on the width of the road; no tree should be planted within 2 metres (6 feet) from the outer edge of the shoulder. The trees should be planted zig-zag, as shown in Fig.69.

52. Kilometre Stones

1. All roads should have one kilometre stone (one mile-stone and seven furlong stones) in each kilometre (mile). They should all be set on the left-hand side of the road in the direction of the increase in kilometrage (mileage). The stones should be set 2 to 2.5 m (6 to 8 feet) from the edge of the shoulder, in cuttings, they should be set in specially cut inches, and on high banks, they may be set on specially built platforms.

2. All letters and fitures should be cut into the stone with shaped incision, which facilitates repainting work and prevents errors. The kilometre (mile and furlong) stones should be painted white with black letters as in Fig.71. The letters and figures may be of the sizes shown in the sketch, the thickness being 2 to 3 cm (½ to 1 inch).

53. Guard Stones

1. Guard stones are required.

(a) On high embankments, along both edges;
(b) Along the outer edges of curves, Fig.71-b.
(c) On down stream sides of causeways, Fig.71-C.
(d) At the ends of culvert and bridge parapets, Fig.71ec.
(e) On the road-side of the inner gutters at salients Fig.16.
(f) Along the down-hill side of road at re-embankments, Fig.16.

2. The guard stones may be spaced 1 to 3 m(3 to 8 feet) apart according to circumstances. They may be made either square or quadrant topped, as in Fig.71-a. The curved top looks better, but the square topped stone is cheaper. The should be 1 m.(38)long, and project about 40 cm(15")above ground.

3. Guard stones on causeways should project at least 50 cm.(18")above the paving; further protection can be provided by connecting them with gas-piping or chains or wire ropes, as in Fig.71-d, when it is called the Railing.

4. Guard stones may be provided on the inside of share salient curves to prevent the wheels of carelessly guided vehicles from cutting into the side drains.

5. On forest roads, these may take the form of pickets, about 20 cm.(8") diameter, and 120 cm.(4') long, being driven at least 50(1Rs') into the ground.

54. Boundaries and Boundary Marks

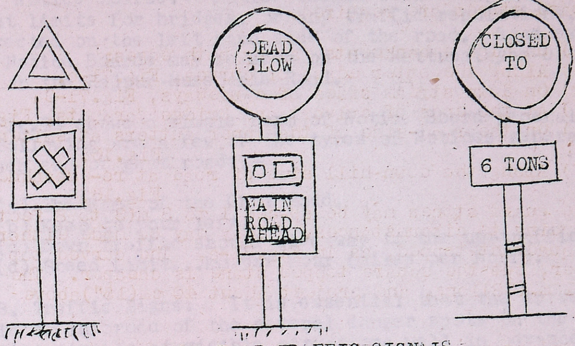
1. Road boundaries should be market at every change of direction; where straight boundaries are long, intermediate stores at every 100 metres(330 feet)should be put in. Near Villages, where encroachments are likely, stones should be put in more frequently, and white-washed annually, Fig.72.

55. Sign posts and Notice Boards

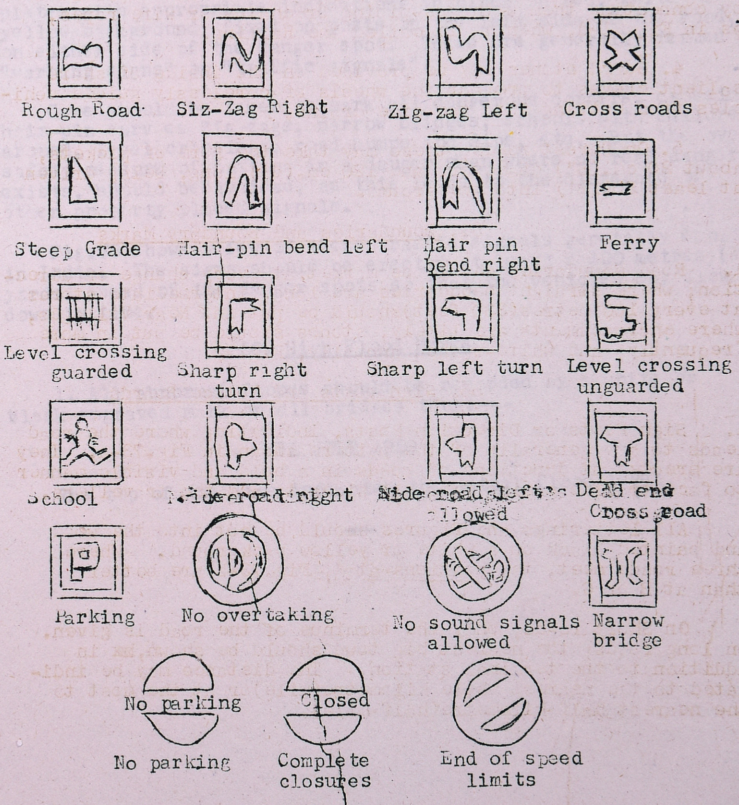
1. Sign Posts or Direction Posts, indicating where the road leads to are generally of the pattern shown in Fig.73-a. They are erected at junctions of roads in a bold and visible manner to face traffic coming from all sides,to aid the travellers.

All letterings and figures should be cut into the wood and painted black on a white or yellow background. Where three roads meet, the positions at A, Fig.73-b are better than at B or C.

On Short roads, only the terminus of the road is given. on long roads, the nearest big town should be shown, ~~xx~~ in addition to the terminal station. The distance may be indicated to the nearest whole kilometre(mile)or at the most to the nearest half-kilometre(half-mile).


DEAD
SLOW
MAIN
ROAD
AHEAD
CLOSED
TO
6 TONS

THE ROAD TRAFFIC SIGNALS


Rough Road
Siz-Zag Right
Zig-zag Left
Cross roads
Steep Grade
Hair-pin bend left
Hair pin
bend right
Ferry
Level crossing
guarded
Sharp right
turn
Sharp left turn
Level crossing
unguarded
School
Side road right
Side road left
allowed
Dead end
Cross road
Parking
No overtaking
No sound signals
allowed
Narrow
bridge
No parking
Closed
No parking
Complete
closures
End of speed
limits

THE DIFFERENT WARNING SIGNALS
Fig: 75 ROAD TRAFFIC SIGNALS

2. Notice Boards:-- Notice Boards indicating speed and weight limits for bridges, or any traffic regulations, should be erected on the left hand side of the road. Good examples of such Notice Boards may be seen on the Mettupalayam-Ootacamund Road or the Rajpur-Mussoorie Road.

Fig.74 shows a simple form of Notice Board generally used, and following are a few of the types of Notices generally erected at each end of ghat roads:-

(a) The Name of the Ghat Road.
(b) Keep to your left.
(c) Down traffic should give way to the up-traffic.
(d) Speed Limit...km per hour (miles per hour).

3. Traffic Signs: It is essential that the travellers should be informed of the several danger spots on the road, by erecting signals at visible situations well in advance of such points of danger. These are generally in the form of metal plates with appropriate indications in black on red, white or yellow background, fixed on posts on the left side of the road, on either side of the danger spot. These are generally termed "warning signs" or "traffic signals".

Care should be taken to mark all dangerous corners, crossings, hair-pin curves Zig-zags, narrow bridges, schools with children around, level crossings, road humps and dips, etc. But the over-safety measure of putting in a dauger sign where no real danger exists, should be avoided, as this leads to the disregard of other properly placed signals.

Fig.75 shows a few of these traffic signals generally employed in India. The signs should be erected at least a 100 metres (100 yards) ahead of the danger spots so that the vehicles may slow down in time.

56. High Flood Marks

1. All abnormal floods should be recorded by a white or black engraved mark on all bridges thus:---

HFL JULY 1959

The top of the line indicates the actual flood level.

PART IV -- BRIDGES

SECTION 9: GENERAL

57. Introduction

1. Forest bridges need only be strong enough to carry a string of loaded carts or elephants and timber lorries. Also forest roads are mainly fair-weather roads, when the bed of the torrential hill streams are nearly, if not quite dry and carts can easily be taken across them; hence mostly irish bridges and causeways are used for cross-drainage in forest roads. In all-weather roads, however, culverts and small timber bridges may be provided; though the length, of such bridges may be considerable it is nearly always possible to construct them of a number of small arches or girder spans, the individual spans of which need not ordinarily exceed 3 to 6 metres (10 to 20 feet).

58. Types of Bridges

1. The various types of Cross-drainage works generally used in forest roads are the ford, the road syphon, irish bridge, causeways, pipe, box, arch or timber culverts, arched bridges, timber bridges, cantilever and suspension bridges.

2. The Ford:-- The river bed is cleared of any projecting boulders, etc., and not-holes filled up so that traffic can be passed over the gap during the dry season, These should be located in the straight reaches of the stream. However, atreams which are not fordable at right angles may sometimes to be found crossable in a slanting direction between two bends Fig.76.

The banks of the stream on either side are cut down at a gentle slope so that vehicles can get down to the bed of the stream and up out on the otherside.

A ford is passable safely, when the depth of water is 30 cm (1'0") for motor cycles, 40 cm (1'6") for motor cars, 60 cm (2'0") for trucks and 75 cm (2'6") for bullock carts.

In broad river beds, the position of the ford should be marked by stakes, which may also be graduated to show the depth of water. Rise of water in the stream should be watched and the ford declared closed before it becomes dangerous.

3. The Road Dam:-- This is a single dropwall, Fig.77, on the down stream side of a shallow hillside stream to hold up the road, the up-stream side being at bed level of the stream. The drop wall should be carried well into the inerodible banks. Any debris brought by the water should be cleared after every flood and care should be taken to see that any channel cut in the road surface is filled in immediately to prevent further erosion.

4. The Irish Bridge is a paved dip in the surface of the road not exceeding 6m(20 feet) in span, Fig.78. The full width of formation is dropped to follow the bed of the shallow water-course, and provided with a normal cross-slope of 1 in 12 in hill sections to 1 in 30 in flat ground, on hill sections they should

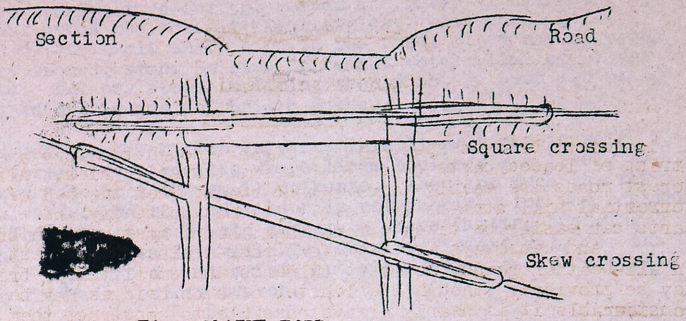

Section
Road
Square crossing
Skew crossing

Fig: 76 THE FORD

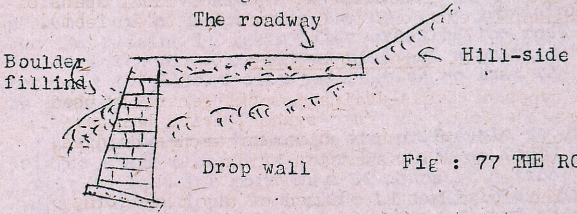

The roadway
Hill-side
Boulder filling
Drop wall

Fig : 77 THE ROAD DAM

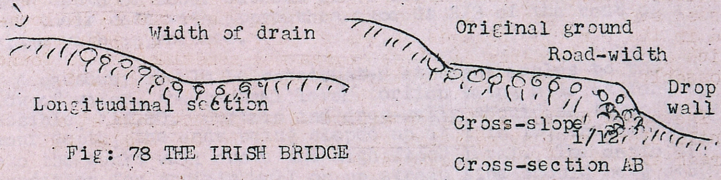

Width of drain
Longitudinal section
Original ground
Road-width
Drop wall
Cross-slope 1/12
Cross-section AB

Fig: 78 THE IRISH BRIDGE

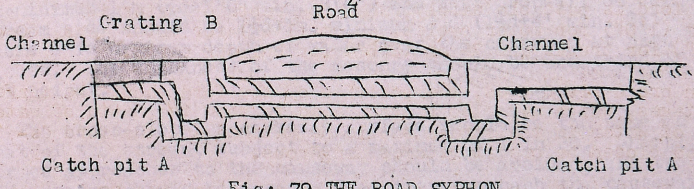

Z
Road
Grating B
Channel
Channel
Catch pit A
Catch pit A

Fig: 79 THE ROAD SYPHON

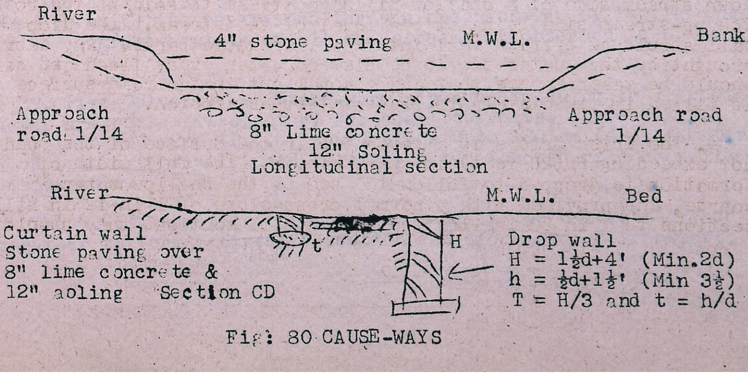

River
4" stone paving
M.W.L.
Bank
Approach road 1/14
8" Lime concrete
12" Soling
Approach road 1/14
Longitudinal section
River
M.W.L.
Bed
Curtain wall
Stone paving over 8" lime concrete & 12" aoling
Section CD
t
H
Drop wall
H = 1½d+4' (Min.2d)
h = ½d+1½' (Min 3½)
T = H/3 and t = h/d

Fig: 80 CAUSE-WAYS

be located only at re-entrant curves and never at salients. They must cross the road at right angles, their edges being rounded off to avoid sharp dips in the road. They may be paved with dry stones, stone in lime or cement motar, lime or cement concrete; but dry stone surfacing should not be used except on unmetalled cart-roads and bridle paths.

These are preferable to culverts in hill sections in soft shaley formations, and also where large boulders are likely to come down and block the small culverts. They are much cheaper than culverts, and skilled labour is not required for the construction. They may be used with advantage where lasting bridging material is not locally available, when sufficient data for the design of a bridge do not exist, and when their use is required only in the fair weather season.

5. The Road Syphon:-- A small irrigation or other water channel may be taken under the road, by providing a drop in its bed and raising it again after crossing the road as shown in Fig. 79. A catch pit A on either side and a grating B at entrance are provided to collect silt and rubbish so that the syphon may not be choked.

6. Causeways:-- Causeways are preferable to culverts and bridges where a depth of over 30 cm. (One foot) of water is not likely to last for more than 24 hours at a time, and the consequent interruptions to traffic is negligible. They are unsuitable where depth of scour exceeds 2m (6 feet) and should not be provided when their cost with approaches exceeds 2/3 of the cost of a bridge with approaches.

A causeway should be constructed at right angles to the flow of water, the central level portion being made as long as possible, Fig.80. Curtain and drop-walls should be taken to below scour depth, the ends being sloped up at 1 in 15, and carried into the banks well above the high flood level. The depth of foundation for curtain wall on up stream side should be $\frac{1}{2}$ d+50 cm-minimum 1 m ($\frac{1}{2}$d+1'6" min. 3'6") and that dropwall on downstream side should be $1\frac{1}{2}$d+1m. minimum 2 d ($1\frac{1}{2}$d+4' min. 2d) where d is maximum depth of water over the causeway at high floods. The thickness of the masonry should be one third of its height.

The cross-slope on causeway surface should be the same as that of the stream, subject to a maximum of 1 in 30. Sharply turned approaches to the causeway should be avoided, and the side drains should be eased off as they approach the causeway. In wide straggling streams with two or more stream, these should, when practicable, be trained through one causeway of length equal to the aggregate width of all the streams at observed high flood level.

7. Pipe Culverts:-- Stone-ware pipes up to 60 cm (2') in diameter are quite satisfactory for shall culverts, while C.G.I., cast iron and hume (P.C.C. spun) pipes upto 120 cm (4') diameter have been extensively used to carry water through road or railway embankments.

The C.G.I, sheeting culverts are made in two halves fastened together to form a circular section and are easy for transport.

The thickness of sheeting should not be less than 18 S.W.G., and they require a 15 cm (6") packing of lime or cement concrete all round in permanent structures. The sheets should be of the rustless variety and ARMCO is one of the well-known, available in 45,60,90 and 120 cm (18",24",30" and 36") diameters.

Each end of the pipe culvert should be protected by a head-wall as shown in Fig.18, and joints in the pipes should be well-caulked with hemp rope and cement mortar (1:2), care being taken to prevent the water from forming false channels on the pipes. The length of the pipe line should extend across the full width of the embankment at the toes, and should be given a fall of 1 in 15 to 1 in 20. Where several pipes are jointed, they should be laid with an initial camber of 2 cm (1 inch) at the centre for every metre (5 feet) vertical height of bank. A minimum earth-cushion of 60 cm (2') should be provided over the pipe, to absorb the effect of impact. A catch-pit should be provided at the inlet end of the culvert, with its bottom at least 30 cm. (12") below the invert to collect silt carried by the water.

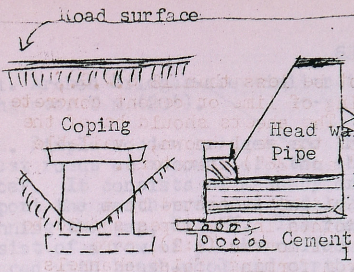
8. Box Culvert:-- Small culverts providing upto 1 or $2m^2$ (10 to 20 sft) of water-way may be built of roughly squared stones set dry or in mortar and spanned by stone slabs, as shown in Fig.82. A usual mistake is to provide a common pavement of small stones to serve as foundation on which both the abutments are built up; this is not quite satisfactory since both the walls also will be loosened when the pavement stones are scoured. It is better to provide independent foundations for each abutment, and an invert of rough stones for the floor of the culvert.

The thickness of the slab-cover depends upon the span of the opening and also on the thickness of earth-cusion in top; granite slabs of 20 to 40 cm (8" to 15") in thickness are quite sufficient for spans of half to one metre (2 to 4') respectively, when the bank above is at least 1 metre (3 to 4') high.

9. Arched Culverts:-- When the span of the opening exceeds 1.5 metres (5'), arched culverts of stones, bricks or concrete, are generally adopted in all-weather roads. Care should be taken that these do not form a hump in the road, since it will tell very hard on the springs of motor vehicles.

The arch may be semi-circular or segmental, Fig.83, the latter having the advantage of giving a greater water-way for a given span; although the segmental arch requires a greater thickness of arch ring, and produces a thrust on the abutments, the stresses in it are more evenly distributed, and hence it is the one most commonly adopted for bridges.

10. Timber Culverts:-- Round poles may be used for culverts as shown in Fig.84. The hard-wood posts, 15 to 20 cm (6 to 8") diameter, are shod and driven 1 m (3') into the ground on each side of the gap, at intervals of 1 to 1.2 m (3 to 4'), and they project about 1 m (3') above the road level to act as rail posts. Short intermediate poles are then driven 1 m (3') into the ground along each bank and opposite to one another, their tops being about 30 cm (1') below the road level, short horizontal struts are then placed between each pair of posts and slightly notched into them. The top of the culvert is then covered with round poles about 20 cm (6 to 8 in.) in diameter placed side by side in the direction of the roadway. A light layer of brush-wood is laid over the round poles and earth spread over it to a thickness of 30 cm (1').


Road surface
Coping
Head wall
Pipe

Dig.81 PIPE CULVERT

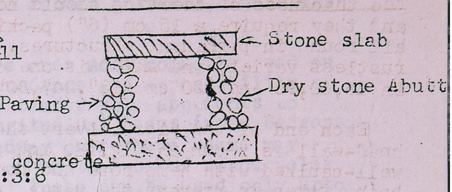
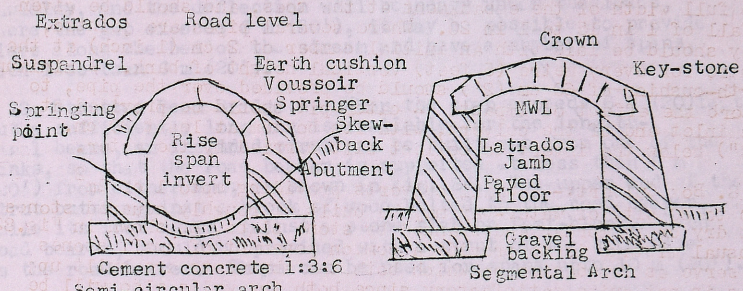

Stone slab
Dry stone Abutt
Paving
Cement concrete
1:3:6

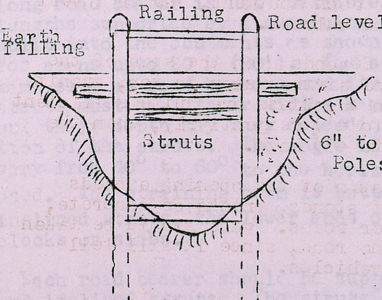
Fig.82 BOX CULVERT


Extrados
Road level
Suspandrel
Earth cushion
Voussoir
Springer
Springing point
Rise
span
invert
Skew-back
Abutment
Cement concrete 1:3:6
Crown
Key-stone
MWL
Latrados
Jamb
Payed floor
Gravel backing

Semi-circular arch

Segmental Arch

Fig.: 83 THE ARCH CULVERT


Railing
Road level
Earth filling
Struts
6" to 8"
Poles

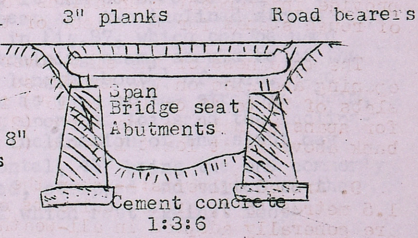

3" planks
Road bearers
Span
Bridge seat
Abutments
Cement concrete
1:3:6

Fig. 85 SIMPLE WOODEN BRIDGE

Fig. 84 TIMBER CULVERT

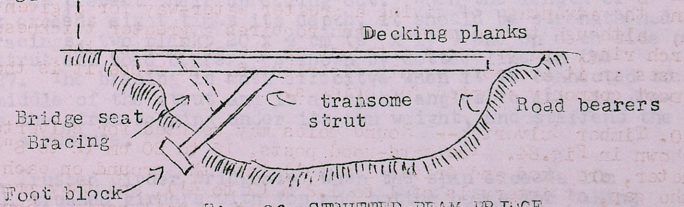

Decking planks
transome
strut
Road bearers
Bridge seat
Bracing
Foot block

Fig: 86 STRUTTED BEAM BRIDGE

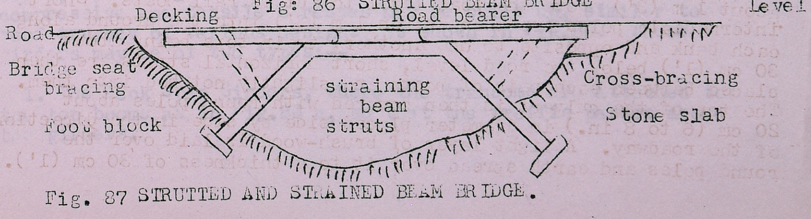

Decking
Road bearer
Road
Level
Bridge seat
bracing
straining
beam
struts
Cross-bracing
Stone slab
Foot block

Fig. 87 STRUTTED AND STRAINED BEAM BRIDGE.

11. Arched Bridges are similar to arched culverts, the spans being over 6 m (20').

12. Simple wooden bridges are the ones most commonly used on forest roads on account of the abundance and accessibility of timber. It consists of masonry or timber pole abutments to support the earth-pressure and longitudinal beams (road bearers, spanning the gap, Fig.85. The roadway over these beams may consist of a row of planks nailed on to them or of round poles covered with brush-wood and earth. These can be used only upto 6 m (20') span, as beyond that span they become too bulky and unwieldy, and the deflection will be heavy under the loads, Where the gap exceeds 6 m (20'), it may be possible to provide piers along the bed of the stream and have a number of spans, each less than 6 m (20').

13. Strutted Beam Bridge:-- When the span exceeds 6 m (20)feet but a sufficiently long log is available for the longitudinal beams, an inclined strut can be built out from one of the banks, so that the road bearer is supported at less than 6 m (20') from either end, as shown in Fig. 86. The upper end of the strut butts against a block of wood bolted to the road bearer, while its foot rests against a stone slab or foot-block. Each road bearer, should be provided with a strut of the same size as the road bearer. These can be used for spans upto 10 m (30').

14. Strutted and strained Bream Bridge:-- When sufficiently long road bearer is not available, it can be made of two or three lengths supported by a straining beam and two inclined struts built into the abutments as shown in Fig.87, which can be used for spans upto 20 m (60'). The straining beam, should be of the same size as road bearers and its length about $\frac{1}{3}$ of span. The struts must have their widths same as that of the straining beam, but their depth may vary depending upon the loadsand the inclination of the struts. The angle of inclination of the strut may vary from 40° to 60° to the horizontal, 45° being the one commonly used. The straining beam is butted, strapped and bolted to the inclined struts, the lower ends of which rest against foot-blocks or slabs.

Each road bearer should be supported by a straining beam and inclined struts. The struts are tied together by cross-pieces to prevent their spreading out. When the length of a strut exceeds eight times its depth, it should be strengthened by bracings, two planks 20 x 4 cm (9" x 1½") one on each side of the strut and road bearer, as shown by dotted line in the Fig.87. The bracing is most effecitve when it is connected to the middle of the strut and is at right angles to it; it prevents the strut sagging under its own weight, and stiffens the whole structure.

15. Trussed Girder Bridges:- When the span exceeds 10m (30'), trussed girders with top and bottom booms for taking compressive and tensile stresses may be built up, similar to roof trusses of various designs, as shown in Fig.88. These girders may be of two types:--

1. The Deck Span Girders, where the transoms are attached to the top booms as in Fig.88 a, so that the traffic passes above the girders.

(2) The Through Span-Girders, where the transoms are attached to the bottom booms, as in Fig.88b, so that the vehicles pass between the two main girders.

The Through span girders have the advantage that they do not obstruct the waterway in the least so that the level of roadway need not be raised unnecessarily as in the case of a deck span bridge. In the case of the deckspans, however, a great number of girders can be used to provide the necessary width roadway so that each individual girder need not be very big or unwieldly, as in the case of through span bridges where only two main girders can be used, one on either side of the roadway.

16. Cantiever bridges consist of two systems of counter-poised beams built out from the two abutments, and supporting road-bearers in the middle. Each system consists of beams placed one above the other, so that the end of each projects beyond the enough to enable it to be connected by means of a single road bearer, Fig.89. The contilever beams are built into the abutments and weighted down sufficiently such that the centre of gravity of each system of cantilever falls well within the middle third of the base of the abutment, which is generally of rubble stones strengthened by wooden frames.

These are very cumbersome to build and wasteful of materials and hence they are fast becoming obsolete, being replaced by the more easily built suspension bridges.

17. Suspension bridges:- These can be constructed across large openings which do not admit of intermediate piers, either on account of swift flowing water or a deep gorge. In forest roads, these are rarely required for heavy traffic but may have to be constructed for carrying laden animals and men or jeeps.

A common suspension bridge consists of a roadway suspended by cables passing over the tops of piers and connected to anchorages on either bank. The roadway is suspended from the cables by means of wire rope slings or specially made hanger roads -- as shown in Fig.90.

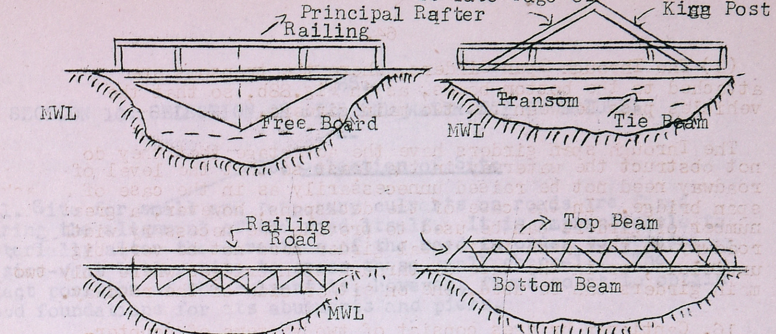
The stability of the whole bridge depends upon the strength of the anchorages and the site should be so chosen that anchorages are constructed in sound rock or hard soil.

The cables normally consist of steel wire-ropes, but for light, temporary bridges, codage, fibres, creepers or even country ropes may be used.

The piers will normally be made of timber frame-work or of steel girders or masonry pillars with R.C.C. or steel beams or arches on top.

The roadways consists of transoms, road bearers, deckings, wheel-guides, and railings attached to the transoms.

To face Page 64


Principal Rafter
Kigg Post
Railing
MWL
Free Board
Transom
Tie Beam
MWL
Railing
Road
Top Beam
MWL
Bottom Beam

(a) DECK SPAN BRIDGES (b) THROUGH SPAN BRIDGES

Fig.88 TRUSSED GRIDER BRIDGES

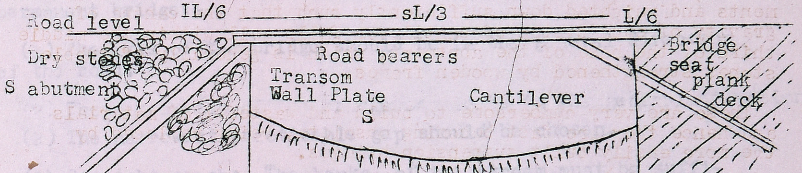

IL/6
sL/3
L/6
Road level
Dry stones
S abutment
Road bearers
Transom
Wall Plate
S
Cantilever
Bridge seat
plank deck

Fig.89 CANTILEVER BRIDGE

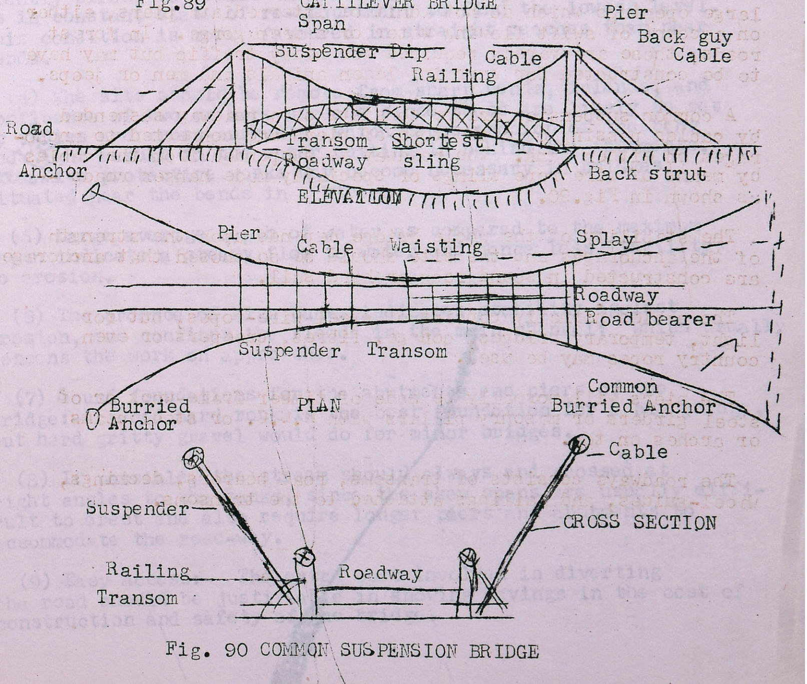

Span
Pier
Back guy Cable
Suspender Dip
Cable
Railing
Road
Transom
Shortest sling
Roadway
Anchor
Back strut
ELEVATION
Pier
Cable
Waisting
Splay
Roadway
Road bearer
Suspender
Transom
Burried Anchor
PLAN
Common Burried Anchor
Cable
Suspender
CROSS SECTION
Railing
Roadway
Transom

Fig. 90 COMMON SUSPENSION BRIDGE

SECTION 10: SELECTION OF SITE AND WATER-WAY OF BRIDGES

59. Selection of Site

1. Site for small and temporary culverts on roads are fixed during the alignment of the road itself. It is impracticable to materially alter the direction of the road in order to obtain a sime-what better site to cross these small channels. The exact position of the culvert is, however, fixed so as to obtain good foundations for its abutments and piers.

2. For big and permanent bridges, the best site for the construction of the bridge should be first selected, before the alignment of the road is finally pegged. These are often made obligatory points so that the road may have to be diverted points to be borne in mind while selecting the site for a permanent bridge:-

(1) The axis of the bridge should be in the general direction of the road.

(2) The [illegible] bridge [illegible] be in the general direction

(2) The narrowest practicable gap should be chosen.

(3) Straight reach: The banks of the stream must be sufficiently strong to resist the eroding action of the stream; which is in constant state of re-adjustment to find the lowest level. This condition is more favoured in straight reaches than near bends.

(4) The site should be remote from sharp bends, inlands, and confluence of two or more streams since these are likely to set up eddies and cross-currents, which cause erosion of the bank and might result in the water cutting in behind the abutments. Extensive protective works may become necessary in bridges situated near the bends in a stream.

(5) Large average depth of water as compared to the maximum depth indicate a steady flow to water and hence less liability to erosion.

(6) The preence of high banks indicates stability against erosion, and confines the floods in the main channel; which usually lessens the work on approaches.

(7) Sound foundations for the abutments and piers of the bridge:-- Good hard rock is the best foundation for a big bridge, but hard gritty gravel would do for minor bridges.

(8) If possible, the stream should always and crossed at right angles to the banks, since the skew spans are usually difficult to erect and also require longer piers and abutments to accommodate the road-way.

(9) Easy access:- The extra cost involved in diverting the road should be justifiable in showing savings in the cost of construction and safety of the bridge.

(10) Approaches:- (a) A straight approach for at least 50 m (50 yards) on either side of the bridge should always be aimed at. If it is impracticable to provide straight approach roads, proper super-elevation, extra-width and clear vision must be provided at the approach curves.

(b) Level approach roads are the best; in any case, the gradient on approaches should not exceed 1 in 20.

(c) The height of the bridges should be such that the work on approaches is reduced to a minimum.

(d) Long and deep cuttings on approaches should be avoided, as otherwise special drainage works will become necessary.

(e) They should be well above the highest **flood** level to prevent the water topping the approaches and cause a wash away.

60 Provision of Waterway

1.General:- Waterway is the area of the clear openings under the culverts and bridges through which water is allowed pass. An adequate waterway should be provided for passing off maximum amount of water reaching the bridge site at any one time so that there is no risk of damage by the flood waters.

2.Free Board:- Where there is no drift timber in the strea the actual waterway is calculated upto about 60cm (2') below lowest level of a girder bridge or 60 cm (2') below the spring level in the case of an arch bridge; but where the spream is to bring in a large amount of drift timber, the waterway is calculated only upto about 3 2 m (6') below the lowest portion of the superstructure or the springing level of the arch bridge. This extra clearance above the expected maximum water level in the iscalled "Free Board" - See Fig. 83 and 88.

When large spans are involved the following "Free Board" above M.W.L. prescribed by the Indian Road Congress may be used.

Clear Span	Free Board	
	Girder Bridges	Arch Bridges
3m(10')	30cm (1') below soffit	Rise of arch
6m(20')	60cm (2') "	
15m(50')	1m (4') "	¾ Rise or 2.5m (8')
25m(80')	1.5m(5') "	Whichever is less
40m(120')	1.8m(6') "	2/3 Rise or 4m (12')
50m(150')	2m(7')	whichever is less.
60m(200')	2.5(8') "	½ rise or 5m (16')
100m(300')	3m (10') "	whichever is less.

3. The Chief factors governing a correct estimate for the waterway required for a bridge are:-

(a) The area of catchment:-- Larger the area of the land drained by the stream, larger will be the waterway required.

(b) The maximum rainfall and intensity of rainfall. Also floods are not caused by the first heavy rains but by the subsequent heavy rains when the ground is fully soaked.

(c) The shape of the Catchment:-- In a long and narrow catchment, the discharge from the lower reaches is likely to have passed off before the water from the distant reaches arrive at the bridge site, whereas the flow from all parts of a semi-circular catchment will tend to arrive at the bridge-site simultaneously.

(d) The character and inclination of the catchment area:-- Steeper the slopes, greater will be the flow; also the flow from a barren, rocky area will be much more than areas covered with forests.

(e) Permeability and inclination:-- A large amount of water falling on permeable soil may sink underground and leave the valley while the vegetation on the soil will hold up and retain a large amount of water.

(f) The condition and inclination of the bed of the stream:-- Larger amount of water reaching the stream will pass under the bridge, if the bed is rocky and impermeable with steep slopes than if the bed is flat with permeable soil.

(g) Section of the culvert and inclination of the invert:-- If the invert can be given a slightly steeper slope than the bed of the stream, a smaller waterway will suffice, since the velocity of flow will increase.

(h) Nature of streambed, which determines the amount of afflux that can be allowed.

4. Afflux is the amount by which the water level on the upstream side of the bridge is raised above the normal maximum water level, due to the obstruction caused to the natural flow of the water by the construction of the bridge. Consequent on the rise of water level, the velocity of water under the bridge will be increased, which must not be allowed to exceed the scouring velocity for the soil in the bed of the stream; in soft soils, a 10 cm (4") afflux is sufficient to start scour, whereas hard rock can safely withstand 1 m (3') of afflux.

5. Flood discharge:-- The most reliable method of estimating the maximum flood discharge from a catchment area is by calculating what the discharge would be at the observed high flood level (H.F.L.). It is enough to choose the highest flood observed in the past twenty five years, adding 10 per cent for a margin of safety and to calculate the water way required on this basis. If there are no records, the local inhabitants must be consulted and flood marks searched for and a substantial margin should be allowed for in such cases.

It should be remembered that the discharge should never be estimated from the first floods of the rainy season, since after the dry season the ground will absorb a considerable amount of water. The estimate should be based on observations after the ground is saturated.

6. Waterway for culverts and small bridges:-

(i) One approximate method of computing the water-way is to find the drainage area and mark an opening large enough to carry off 10mm (3 to 4 inches) of rainfall per hour.

(ii)Another rough method for culverts in hilly country, for catchment areas upto 250 hectares (1 square mile) is to allow at the rate of 3 cm width of water-way per ha(20' per sq. mile) of area. Thus for a catchment area of 200 ha ($\frac{3}{4}$ sq.mile) a small bridge of 6 metres (15 feet) span should be adequate.

(iii)A third approximate formula for cross-drainage works over nalas with catchments upto 250 ha (1 sq. mile) as adopted by the Bombay Public Works Department is as follows:--

If x be the number of hectares, (acres) in the catchment,

(a) For areas up to 40$_2$ha. (100 acres).
water way $a = .1xm^2$ (or $.4x$sq.ft.)

(b) For areas over 40 ha.$_2$to (100 acres), wa-terway is given by $a = 0.055 x 1.8 m^2$ ((0.225 x + 17.5 sq. feet).

(iv) Talbot's formula:-- $a = C \sqrt[4]{A^3}$

When a = area of opening in square feet
A = drainage area in acres,

and C = 1.0 for very mountainous country with steep slopes;
= 0.8 for hilly areas;
= 0.5 for undulating cultivated country.
= 0.2 for flat ground.

The following table gives waterways calculated from Talbot's formula--

A-REA OF WATERWAY FOR CULVERTS

Drainage area (A)		Area of waterway in square feet(a)			
Acres	Sq.miles	Mount-ainous land	Hilly land	Rolling land	Flat ground
Acres		C = 1.0	C = 0.8	C = 0.5	C = 0.2
1	0.0016	1	0.8	0.5	0.3
2	0.0031	1	1.4	0.8	0.5
4	0.0062	2	2.2	1.4	0.8
6	0.0094	3	3.0	1.9	1.1
8	0.0125	4	3.8	2.4	1.4
10	0.016	5	4.5	2.8	1.7
15	0.023	7	6.1	3.8	2.3
20	0.031	9	7.6	4.7	2.8
30	0.047	13	10	6.4	3.8
40	0.062	16	13	8	4.8

60	0.094	22	18	11	6.6
80	0.125	27	22	13	8.1
100	0.156	32	26	16	9.6
150	0.234	43	34	21	13
200	0.312	53	42	27	16
250	0.39	63	50	31	19
300	0.47	72	58	36	22
400	0.62	89	71	45	27
500	0.78	106	85	53	32
600	0.94	121	97	61	39

Note:- The above formula is based on a peak rainfall intensity of 4 inches per hour. Adjustments should be made for larger intensities of rainfall.

However, these formulae can all be used only as a guide in connection with the local conditions. In the case of small culverts, the passage of mud and stones must be allowed for hence no culvert should be less than 1 x 1 m (3'x3').

(v) The requirements for a large span bridge are many, and as forest bridges are rarely of any big spans a discussion for the large bridges are beyond the scope of this volume.

61. Scour

1. General:- The action of rapidly flowing water on the soil on which it flows, resulting in moving the soil and small solid particles is known as Scour. It should be remembered that the velocity at the side and bottom of the stream is always less than its mean surface velocity.

The effect of different velocities of water in scouring various soils is given below, which can be used as a guide.

0.25 foot per second will scour fine clay, river mud, or silt.
0.50 " fine sand or common clay
1.00 " fine gravel.
2.00 " 1 inch shingles.
5.00 " conglomerate.
10.00 " hard rock.

Chailby's formula for velocity of water which will move stones is of interest--

$$V^2 = 85 D,$$

where V = velocity of water in feet per second
and D = diameter of stone moved in feet.

2. Effect of obstruction:- Scour develops in the first instance by the swirling action of the water forming a pot-hole. A pot-hole occurs whenever an obstruction such as a bridge pier or abutment or a spur projects into the general current of water, shielding a body of water on one side. The shielded body of water is formed into an eddy by the main current brushing past one side of it, and it is this swirling action which scops out the pot-hole; these pot-holes should not be allowed to come dangerously nea-r the foundation of the structure.

The action of scour is found to be the greatest when a river is rapidly rising or falling, and not during the period of full flood. As a result of floating logs and wreckage getting piled up across narrow openings, the current may be forced to undermine the foundations, for this reason, the piers of bridges are usually tapered to a point in plan so that these divert the debris into the opening.

3. Precautions against scour:-- The practical remedies to minimise or prevent scour are:--

(i) Take the water direct through the bridge-opening employing guide banks or spurs if necessary.

(ii) Provide ample water-way, and leave no sharp ends.

(iii) Use deep foundations (below scour depth) for piers, and also construct abutment piers.

(iv) Surround the pier bases with an apron of stone 60 to 100 cm (2 to 3') thick.

(v) Provide a stone-pitched floor or paving between piers, or 20 to 30 cm (12") thick concrete or brick-in cement pavement.

(vi) When pot-holes occur, fill up that area immediately with stone or quarry refuse.

(vii) Provide curtain walls on the upstream side and drop-walls on the down stream side.

(viii) Secure a uniform depth in the water-way.

SECTION 11: MASONRY ARCHED CULVERTS

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62. General

1. Definitions:- Fig.83 shows the different parts of an arched culvert. Since the piers and abutments may be battered dowrwards, the span is the clear distance between the faces of abutments and piers at the springing level. The individual wedge-shaped blocks forming the arch ring are called Voussoirs. The point from which the arch springs is called Springing point, and the first voussoir is termed the springer. The line joining all the springing points is known as the springing line, and the level of this line is the springing level. The inner surface of the ring is known as Intrados or soffit of the arch; while the outer face is known as its back or Extrados; the highest point of the extrados is known as the Crown of the arch, and the central voussoir is called the Key Stone. The lower half of the extrados is termed the haunch of the arch, while the triangular space between the vertical through the top of skew back, horizontal through the crown and the extrados, is called spandrel. The inclined surface on which the springer rests in called the skew-back and the block which contains this inclined surface is also sometimes known as skew back. The end supports of a bridge or culvert are known as abutments, while any intermediate supports a-re termed piers.

2. Span:-- The span to be adopted depends mainly on the water-way

to be provided. It should be remembered that the springing point should be at least 30 cm (one foot) above above the afflux level provided. Large arches are more troublesome to build than small ones, and it is often preferable to build a number of small arches instead of one large span arch; large arch rings require large blocks of stone to be quarried, thus increasing cost; large arch also means an increase in the height of road-way above the river-bed which will increase the sizes of piers required.

An economical span would be one which is about 1.0 to 1.2 times the height from under the foundations to the crown of the arch (assuming an approximate size of arch ring). Spans greater than this will reduce cost very slightly but those less will increase cost very considerably.

3. Rise:- Rise of the arch is the height of the under-side of keystone above the springing level. A semi-circular arch can be built with minimum of material, but it has the disadvantage of raising the road-way unnecessarily, and the stresses are also not well-balanced; a segmental arch is therefore, preferred and one with a rise of ⅓ to 1/5 span is about the best; the quarter-span rise is the one most commonly adopted.

4. Springing line:-- As a rule, the springing line is taken at one level for all the arches in a bridge, but when there are land arches of smaller spans than the main arches of the bridge, the springing points are taken at higher levels so that the crowns of all the arches are at the same level.

63. Design of Arches.

1. Trautwine's rules are generally followed in the design of arches, as they have been found very reliable for small spans, and are given below. By geometry,

$$\text{Radius} = \frac{(\frac{1}{2}\text{ span})^2 + (\text{rise})^2}{2 \times \text{rise}} \qquad (1)$$

$$\text{Thickness of arch ring } t = \sqrt{\frac{\text{Radius} + \frac{1}{2}\text{ span}}{7}} + 0.06 \text{ m}$$

$$t = \sqrt{\frac{\text{Radius} + \frac{1}{2}\text{ span}}{4}} + 0.2 \text{ ft.} \qquad (2)$$

For second class masonry, increase thickness by 1/8, and for brickwork or fair rubble increase it by ⅓.

Thickness of abutment at springing level, Fig.91

$$T = AE = \frac{\text{Radius}}{5} + \frac{\text{Rise}}{10} + 0.6 \text{ m}$$

$$T = \frac{\text{Radius}}{5} + \frac{\text{Rise}}{10} + 2 \text{ ft.} \qquad (3)$$

2. To design the back of the abutment -- proceed as follows, Referring to Fig.91.

from B draw BD such that TD = 1/24 span. Draw FEM parallel to BD, and make EF equal to half of CT, from F draw tangent [illegible] to mark the top of spandrel backing.

Through A draw AH at a batter of 3 vertical to 2 horizontal to cut the line FEM at H. If H lies below the proposed base, PEH is then the back of the abutment. If not, add $HH_1 = \frac{1}{4}GK$ and draw $LH_1\ F_1$ parallel to BD making FF_1 equal to $\frac{1}{2}$ CT, and draw tangent $F_1\ X_1$. If after this addition KL is still less than half of AK then make the base equal to half the height, and draw a back line parallel to BD as before.

These additional thicknesses are to provide against the earth thrusts rather than the thrusts of the arch, and hence should not be applied to abutment piers.

3. Spandrels: The triangular space is partly filled by the backing on which the head-walls are erected and partly by the filling on which the road is constructed and which is retained by the head-walls. The backing is of solid coursed masonry or concrete, and its function is to prevent the arch from spreading under the load, hence it must be of sufficient height so that its weight will counteract the horizontal thrust in the arch. A rough guide would be to draw a line through the centre of the arch inclined at 45° to the vertical and to construct the backing up to the point in which this line cuts the extrados of the arch. The top surface of the backing should be made sloping towards the head-walls in order to drain off any rain-water (percolating through) the road surface by means of weep-holes provided in the head-walls. The filling above the backing, over which the road is constructed is generally of rubble or quarry refuse.

The level of the roadway must be such that there is a minimum the back of the arch ring, pillars are constructed at short regular intervals on which transoms and road bearers are constructed to bring it up to the road level. Alternatively, tall narrow arches, are constructed on the backs of the large span arches, as shown in Fig.92, to reduce the weight of filling required to bring up the level to that of the road.

64. Abutments and Piers

1. Abutments:- When the culvert spans a deep ravine or eroded water-course with high permanent banks, and where there is no danger of the stream eroding round the abutment, the abutment is built as a rectangular mass of masonry with return walls as shown in plan in Fig.93. The return walls also have to take the full thrust due to the live load, and hence it is usual to make the return walls of the same diamensions as the abutment.

The foundation of the abutment must be taken deep below the scour-depth, but the returns may be stepped up as they reach into the sound back. The return walls must be well-bonded into the abutment. The length of the returnwall behind the abutment is generally kept about two thirds of the span.

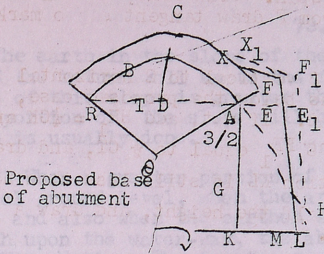

C
X
X1
F1
B
F
R
T
D
A
E
E1
3/2
θ
Proposed base of abutment
G
H
K
M
L

Fig.91 DESIGN OF THE ARCH ABUTMENTS.

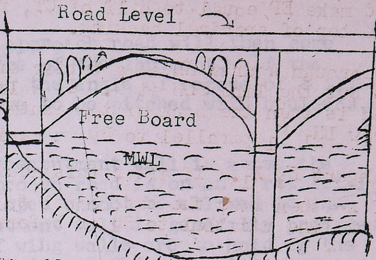

Road Level
Free Board
MWL

Fig.92 THE OPEN SPANDREL ARCH

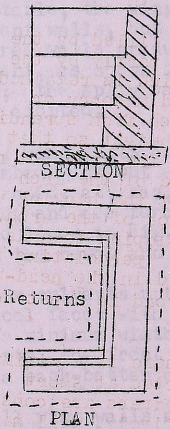
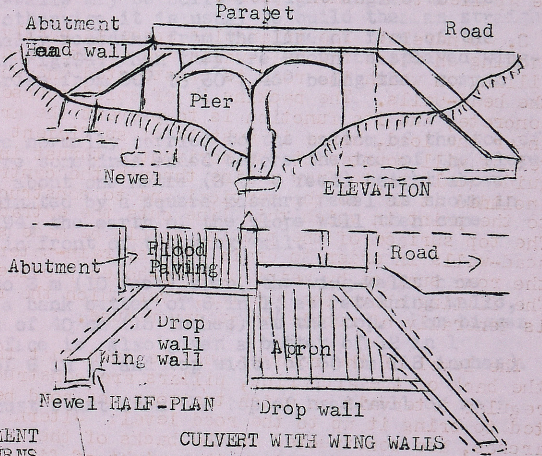

SECTION
Returns
PLAN

Fig.93 THE ABUTMENT WITH RETURNS


Parapet
Abutment
Head wall
Road
Pier
Newel
ELEVATION
Abutment
Flood Paving
Road
Drop wall
Wing wall
Apron
Newel
HALF-PLAN
Drop wall

CULVERT WITH WING WALLS

Fig. 94

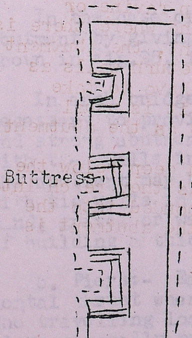


Fig.95 LONG ABUTMENT WITH BUTTRESS

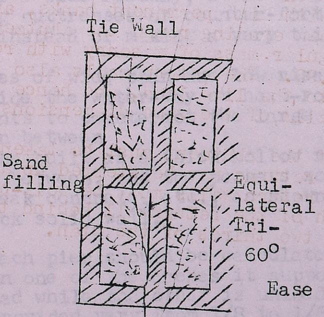

Tie Wall
Sand filling
Equilateral Tri-60°

Fig.96 WIDE ABUTMENT WITH THE WALLS

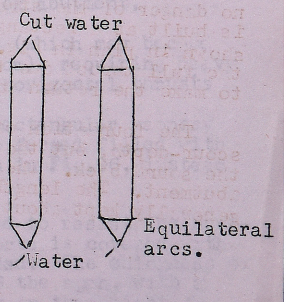

Cut water
Equilateral arcs.
Ease
Water

Fig.97 CUT AND EASE WATERS.

The earth in the slope of the approach road will then come round the return wall up to the face of the abutment. If the angle of this slope is greater than the angle of repose of soil, this portion of the slope will have to be pitched with boulders, which is usually done.

2. When a greater portion of theabutment wall is above the general ground level, when the approach road is on an artificial bank, and also when the earthen slopes cannot be allowed to encroach upon the water-way, the abutment wall is generally provided with Wing-Walls. The functions of wing walls are to hold up the earthern slopes at the rear, and to divert the water into the opening without eroding the banks. When the banks are well-defined and stable, the wing-walls may be built at right angles to the abutment walls, but otherwise it is usual to build them as straight battered walls gradually receding from the line of face of the abutment, as shown in Fig.94, when they are known as splayed wing-walls; the splay varies from 30° to 60°, 45° being the common splay adopted.

3. Wing-walls are normally carried to the bottom of the toe of the embankment but are sometimes ended before the toe of the slope is reached, at, say, about one metre (3 to 4 feet) height above ground, and are terminated by a square masonry newel as shown in dotted lines in Fig.94, the earth of the slope will then come round the newel and in front of the wing wall.

For culverts upto 3 m (10 feet) span, the wing-walls have vertical faces with a bank batter of 6 in 1, as retaining walls, with a minimum width of 40 cm (15 inches) at the top. For bigger culverts, the front face is also given a batter of 12 in 1 with a back-batter of 6 in 1, and top width of 50 cm (18 inches).

All wing walls must start from the top of head-wall or road level.

4. A stronger abutment will be obtained if the masonry courses are built normal to the back batter as shown in Fig.22, but this will increase the cost since all the face stones have to be dressed to suit.

In the case of a wide roadway, it is usual to strengthen the abutment by giving buttresses or counter-forts to the rear, as shown in Fig.95, instead of making a very thick abutment.

In arch bridges of wide span and low rise (which may become necessary to provide the water-way or head-room), requiring heavy and strong abutments to counteract the large horizontal thrusts with tie walls in between
the abutment may be built as a thick hollow rectangular maonsry with tie walls in between, and the pockets so formed filled with sand, gravel or weak concrete, etc., as shown in Fig.96, instead of building a thick solid wall.

5. Piers:- Each pier should be calculated to resist the horizontal thrust when one of the arches it supports is covered with the travelling load while the other is unloaded. The thickness of piers generally provided vary from 1/8 to 1/6 the span, with a minimum thickness of 60 cm (2 feet) depending on the height of the pier. Short piers are given vertical sides, but high piers

should be given either a batter 20 in 1 or an offset of 10 cm on both sides of the piers at 2m (3" in 6') vertical intervals.

6. Abutment piers:-- In bridges composed of numerous arches, every 4th or 5th pier ought to be strong enough to act as an abutment, in case one of the arches fails under the load; these are known as abutment piers, and have their top-width designed as an abutment, and are given a batter of 10 in 1; high piers 4m (12) and above may, however, be given a batter of 20 in 1 on the sides. These will arrest the distruction on the whole bridge, should one arch fail.

7. Cut and Ease waters:- In order to provide the least resistance to the on-rushing water and to divert it through the openings, the piers are generally pointed on the up-stream side; these are called Cut waters, and may be formed by describing an equilateral triangle in plan with the sides on the ends of the piers, or by a similar triangle with curved sides, as shown in Fig.97. Similarly the piers are pointed on the down-stream side in order to prevent the formation of eddies and cross-currents causing a whirling action resulting in scour; these are termed Ease waters.

8. The bed of the stream between abutments and piers in the case of swift-flowing steams may be paved with rubble or stone slabs or bricks on-edge or even concrete, to prevent scour. To protect the paved flooring from being undermined, a wall is built on its up-stream side, with its foundation taken well below the scour depth; this wall is known as the Curtain-wall. Similarly to protect the downstream end of the paving from being underscroued by the falling water, a retaining wall is built up with its foundation well below the scour depth, and this is known as the Drop-wall, see Fig. 94.

9. Sometimes, to protect the bed of the stream in the vicinity of the bridge against heavy scouring action of a rapidly flowing hill-stream, the floor-paving is extended up and down-stream between the wind walls and even beyond; this extended portion of the flooring, shown in Fig.94, is known as appon. The curtain and drop-walls are also shifted to the ends of the apron.

10. Invert: If the bridge has to sustain a heavy load of earthen bank, or if there is reason to fear a settlement of the abutments and piers, an inverted arch flooring may be built up, which will distribute the load on the soil, uniformly and arrest the squeezing up of the soil into the water-way as shown in Fig.83.

65. Construction of Culverts.

1. Foundations:- The foundation of the abutments, and wing-walls must be seated in sound unyielding soil. The foundations of piers should be taken well below the possible depth of scour, and in loose soils they should be protected by a stone appron. A minimum thickness of one foot of lime or cement concrete (1:3:6) base should be provided of sufficient width to distribute the load uniformly over the soil below. The abutments and wing-walls load uniformly over the soil
are generally built with an offsetted back, as shown in Fig.93 instead of a batter, so that the weight of the earth resting on these offsets may also add to the stability of the walls.

To face page 74

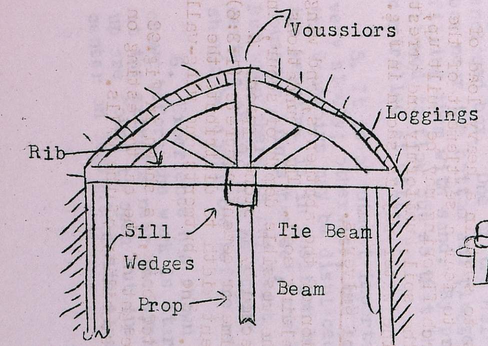
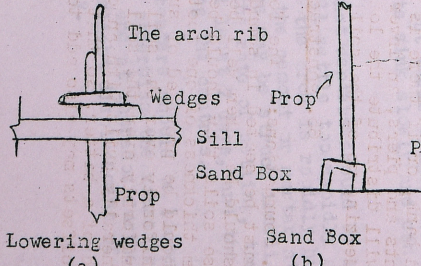

Voussiors
Loggings
Rib
Sill
Tie Beam
Wedges
Beam
Prop

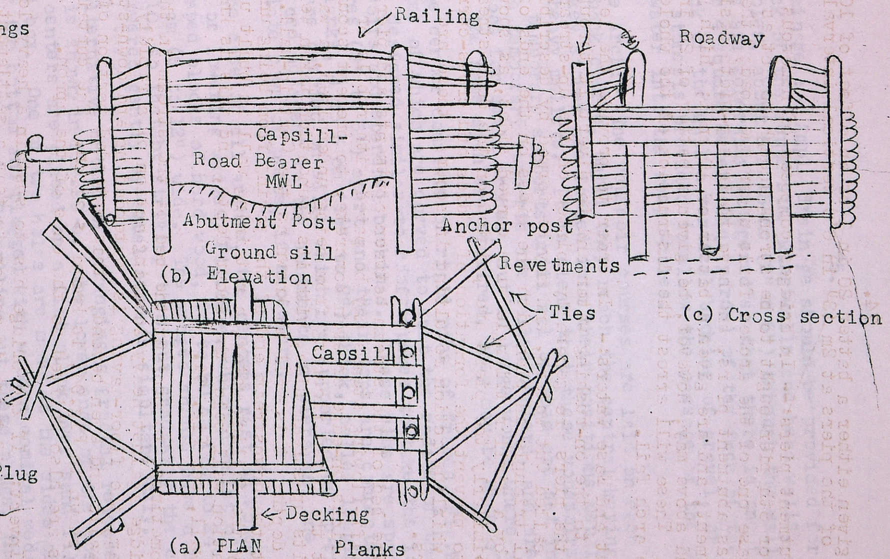
Fig.98 The Arch Centering


The arch rib
Wedges
Sill
Sand Box
Prop
Prop
Plug
Sand Box

Lowering wedges
(a)

Sand Box
(b)

Fig.99 Methods of Easing Arches


Railing
Roadway
Capsill-
Road Bearer
MWL
Abutment Post
Anchor post
Ground sill
Revetments
Ties
Capsill
Decking
Planks

(b) Elevation

(c) Cross section

(a) PLAN

Fig.100 A Typical Wooden Girder Bridge

2. Drainage :- Ample drainage should be provided for the earth at the back of the abutments, wing-walls and head walls, by means of weep-holes, about 5 x 15 cm (2" x 6") through the walls. The weep-holes are generally staggered so that there is one for every 3 or 4 square meters (sq. yards) of the face of the wall. At the back of the wall a vertical backing of gravel, or broken bricks or stonesis provided to allow the passage of the percolating water into the weep-holes.

3. The Arch:- The voussoir courses are laid on each side from the skew-back course, until they reach the central keying course, when the key stones are forced into their positions usually by means of heavy mallets. It is clear that these voussoirs will need some temporary supports until all of them are set in position. The temporary supports are called centers, and are generally made of wood for small arches, but in large works where a large number of the same span are required, they may be made of steel;

4. The center consists of rigid ribs of frames, Fig.98, the upper edges of which are curved to suit the radius of the arch. These are designed similar to roof trusses to take the load of the voussoirs and spandrel backings. These ribs are spaced 1 to 2 metres (3' to 6') apart and their tops are connected with narrow planks, 4 to 5 cm (1½" to 2") thick, called laggings. The centers are carried on sills which are supported by up-rights or props placed adjacent to the abutments or piers and one or two intermediate rows of posts, if necessary.

In the case of all arches, the centers rest on wooden striking or lowering wedges, Fig.99-a, which consist of pairs of wedge-shaped blocks of hard wood, 30 to 50 cm (12 to 24") long and 15 to 30 cm (6 to 12") wide. The wedges should have a long taper of 1 in 10, so that by striking them out gradually the centres may be lowered gently by equal amounts simultaneously.

An alternative method of arranging a gradual release of the centres is shown in Fig.99-b. The lower ends of the posts supporting the centers are placed on a flat plank over sand filled in an enclosed box. One or two holes are made at the sides of the box near the bottom and plugged with wooden conical wedges before filling them with sand. By pulling out these plugs, the sand is allowed to flow out so that the posts sink slowly and can be controlled at will.

5. It is of utmost importance that centers should be lowered very slowly; otherwise, the arch will settle too rapidly and the voussoirs may be displaced. If the arch is rapidly built and the keystone is in position before the cement or mortar at the voussoir joints has set, the centers may be struck immediately. But when there is any doubt as to the rate of setting, the centers should not be struck for at least 7 days, and the backing should be completed before releasing the centres.

6. Experience has shown that centers should be loaded at the crown before the work is started; otherwise the voussoir joints at the extrados near the springing and at intrados further up are found to open out due to a slight displacement of the center on account of its elasticity.

SECTION 12 : SIMPLE WOODEN BRIDGES

66. General

1. Most of the forest road bridges are of small span and are usually built of timber. For forest bridges, a plentiful supply of good timber can usually be obtained near the site at comparatively little cost, and hence the aim is to build a good solid bridge which will last as long as the timber used can be kept free from decay, and which is simple enough to be built by unskilled labour. Joints should be reduced to a minimum, as they collect moisture and start deterioriation.

2. Unless a saw mill is near to the site of the bridge, it is more economical to use round timber for all the heavier parts of the structure, such as girders and posts, as the only expense then incurred will be for felling, dragging, and trimming them. Thinnings from Teak, Sal Deodar or Chir plantations, if available near the site, can be used for revetting abutments and wing walls, but young poles under 20 cm (8") diameter at the butt-end contain too much sapwood to be durable. Round poles are not satisfactory for the decking of a bridge, as they do not give a good smooth running surface unless covered with earth, and any form of earth covering hastens decay.

67. A Typical Small Wooden Bridge

1. The simplest form of bridge consists of a single piece of timber stretched across a gap and is still commonly used for forest-foot-paths. A simple girder bridge consists of several longitudinal beams or road-bearers, laid side by side, and a decking is added to form the road-way. The bank on each side is strengthened to form abutments, upon which the road bearers are supported, and if the gap between the two abutments is large, intermediate supports or piers are added.

2. The exact type of bridge will depend on the span, the nature of foundation bed, the nature of stream or other gap to be crossed, the kind of traffic to be catered for, and the availability of the materials of construction. A typical forest bridge is shown in plan, elevation and section in Fig.100 but the form of every bridge should be adopted to suit the local conditions. The width of the bridge is about 3.5 m (12') giving a roadway about 3m (10') clear width.

3. Appendix 1 gives the formulae generally used in design of bridges Appendix 2 gives dimensions of various members of a simple wooden bridge for carrying a loaded 3 tonne (3 ton) truck, while Appendix 3 gives details of their design.

68. The Abutments

1. The abutments and piers, may be of timber or masonry. The simplest type of abutments is a timber bank seat consisting of mud sills (horizontal planks) about 20 x 8 cm (9"x3"), of a sufficient area to distribute the load over the ground so that the safe bearing capacity of the soil is not exceeded, over the mud sills is placed a bridge-seat, usually a timber baul about

22 x 22 cm (9"x9"), centrally on the mudsills and running at right angles to the centre line of the bridge, to support the road bearers. See Fig.101.

The whole of the bearing surface of mudsills must be in firm ground behind the natural slope of the bank, otherwise the bank may slip down. The bearing area must be rammed solid and properly drained; if water stagnates, either settlement or fracture of the bank will result. Ordinary earth should normally be loaded up to only 5 tonnes per square metre (½ tons per square foot). but in fi gravelly soil or soft rocks the loading may be increased to about 30 tonnes per square metre (3 tons per square foot). The bridge seat must be placed centrally over the mudsills, as otherwide the unsymmetrical loading might cause uneven settlement and result in the collapse of the bearing.

2. Where it is not possible to place timber bank seats above flood level, or where the bank of stream is not well defined and suitable for placing the mudsills, the abutments may be formed of heavy posts about 30 cm (1') in diameter fixed in the ground, and revetted with round poles or planks at the back, to support earthern bank at the rear, as in Fig.100. Three of these are main posts and are sunk below the depth of scour. The other two posts support the wing walls, which are splayed back according to the formation of the bank. These posts may be of some durable species like teak, xylia, sain, deodar or pine. The abutments shown are revetted with round teak or deodar poles of 20 cm (8") diameter obtained from the thinnings of a neighbouring plantation.

The posts are anchored back by wooden ties to a firm anchorage post, sunk into the ground at a distance of 4 metres (12') from the edge of the bank, as seen in plan in Fig.100-a. The three main posts rest on a ground sill, 30 x 15 cm (12" x 6") timber, and are kept in position by means of stub tenons about 8 cm (3") square made on their lower ends. These joggle joints are sometimes difficult to make, and an alternative method is to use dowels. The ground sill must rest on well remmed beds of the foundation trenches.

Two cap-sills of equal size 12 x 25 cm (5 x 9") are bolted into notches cut to receive them near the tops the posts, and a clear added beneath to strengthen the joint. These dapsills support the road bearers, which in turn carry the decking plank.

3. Piles:-- Where the presence of water or loose wet sand prevents excavation to the necessary depth for the ground sills, the posts are driven into the ground and are then called piles. Timber piles are trunks of trees, either round or roughly squared and brought to a blunt point at one end. The posts must be sound, free from large knots or shakes, and straight-grained. With hardwood piles for forest work in ordinary soils, it is rarely necessary to provide iron points or shoes to the piles, but where the shoes are required, they should be fitted closely. If the shoes are lossely fitted, the strain comes on the bolts used and this frequently causes the piles to split, see Fig.102.

The head of the pile should be cut quite square and level;

otherwise the blows of the pile-driver will be received on one edge, and the pile is likely to split. To protect the head of the pile when being driven, an iron ring, about 5 cm deep and 1 cm thick (2" deep and 3/8" thick) is fitted round its head; the outside of the head of the pile is slightly trimmed down for 3 to 5 cm (1" or 2") so that the ring is easily slid on to it, and after two or three blows, the ring will be found to be tightly clasping the pile, see Fig.102.

With a hard-wood pile, there is very little crushing or brooming of the head, but if the pile head splits inspite of the ring, the broken head is cut off and a new ring fitted. It is often difficult to estimate the required length of piles until the first pile is driven, and this should be carefully measured and used as a test pile.

4. Pile driving:-- There are many forms of Pile-drivers, ranging from a maul raised by two men and dropped repeatedly on to the top of the pile, upto large machines with heavy rammers.

Fig.102 shows a type of improvised wooden pile driver that can be conveniently used in Forest works. It consists of a lashed trestle erected in position with guy ropes fastened to pickets. The rope to which the monkey is tied passes though a pulley lashed to the transom. The monkey is guided by means of an iron rod, about 3 cm (1") in diameter, which is fixed to the top of the pile to be driven, and passes through a hole bored down the centre of the monkey. The monkey is generally made of a stump of sal, teak or other heavy wood, about 40 cm (16") in diameter and to
teak or other heavy wood, about
1.5 m (3 to 4 feet) in height. The upper end of the iron guide rod may be passed through a short bamboo tube lashed to the transom, which will allow the rod to descend as the pile is driven in.

Instead of the trestle, a shear or single-pole derrick may be used for supportint the monkey and guide rod.

The pile driving should be continued until the average sett of the pile per blow under the last six blows of the monkey is less than 1 cm (half-an-inch).

In most kinds of soils, the resistance to penetration will greatly increase if the pile is left for 24 hours, and hence the work should not cease for the day until the pile is driven to the full depth. The contractors often attempt to cut off a few metres (several feet) from the pile-head to avoid the cost of driving it, and to prevent this, all piles should be indelibly marked with a personal hammer or iron punch at measured intervals from the point. The marks will show the exact depth of the pile in the ground and enable the progress of the driving to be watched.

When the bridge-posts are in position, the revetment of the abutments is commenced. The round poles are placed with alternate butt ends and small ends together in order to keep the revetments horizontal. The space behind the revetment walls should be filled in with stones or gravel to reduce earth pressure.

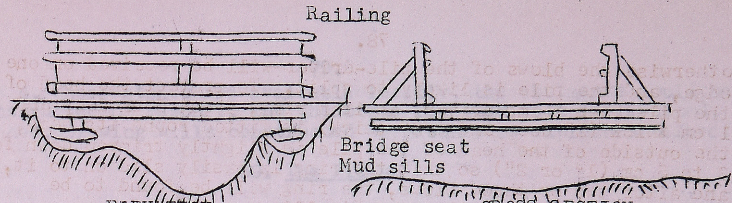
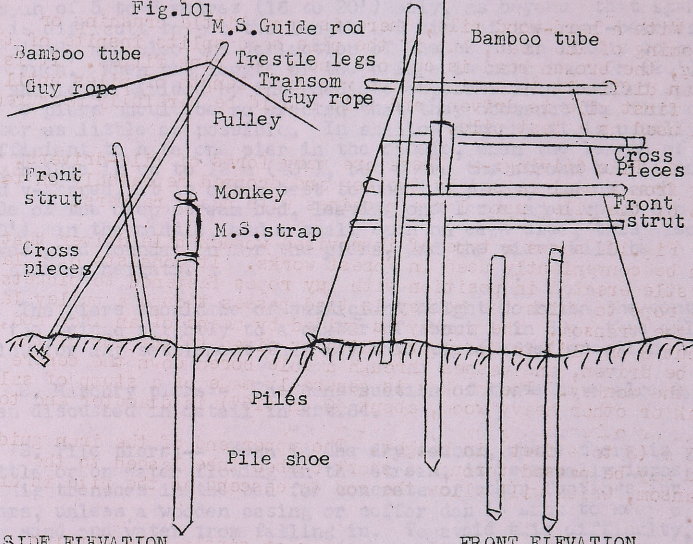

Railing
Bridge seat
Mud sills
ELEVATION
CROSS SECTION

Fig.101 TIMBER BANK SEAT


M.S.Guide rod
Bamboo tube
Trestle legs
Transom
Guy rope
Guy rope
Pulley
Front strut
Monkey
M.S.strap
Cross pieces
Piles
Pile shoe
Bamboo tube
Cross Pieces
Front strut

SIDE ELEVATION FRONT ELEVATION

Fig.102 TRESTLE OR LADDER PILE DRIVER

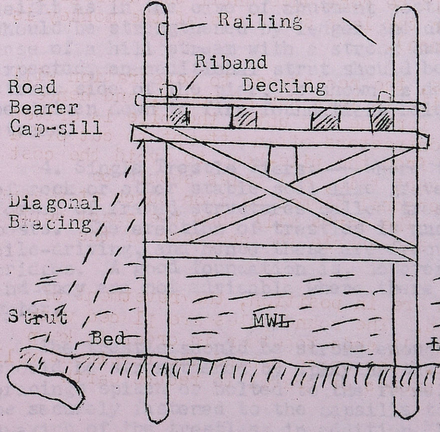
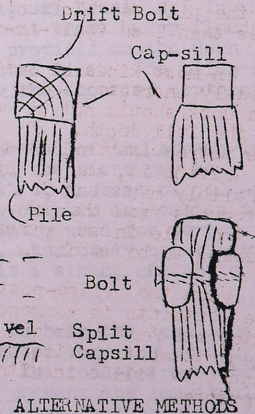

Railing
Riband
Decking
Road Bearer
Cap-sill
Diagonal Bracing
Strut
Bed
MWL
Level

Fig.103 PILE PIER.


Drift Bolt
Cap-sill
Pile
Bolt
Split Capsill

ALTERNATIVE METHODS OF FIXING CAP-SILLs

4. Where stones are available locally, the abutments would be constructed of masonry, and the banks revetted with large-sized stones, or wing walls constructed of masonry as explained before.

69. The Piers

1. A single span bridge with two abutments can be used up to a span of 5 to 6 metres (16 to 20') only, as beyond that span it is difficult to get the length and size of the road-bearers required, and also the deflection of the beams in likely to be too much. When the length of the bridge is more than 6m (20') it should be divided by intermediate supports into smaller spans. These piers should be so erected that they obstruct the flow of water as little as possible. In shallow streams it is usually sufficient to have one pier in the middle, when the length of the bridge is up to 12 m (40'), but where the stream bed is deep and v-shaped, it is often best to use two piers, one on each side of the deep stream bed, leaving one large span up to 6 m (20'), in the middle, and a small span on each side; this also gives good foundation for the piers, and the piers will be of shorter heights.

The piers should be of sufficient height to raise the centre of the bridge slightly to a camber of about 1 in 30; this will allow for any settlement that may take place after erection.

2. Masonry piers:- The construction of these have already been discussed in detail in Art.64.

3. Pile piers:-- Even in the dry season, where there is very little or on water flowing in the stream, it is usually impossible to dig trenches in the bed for concrete or other footings for piers, unless a wooden casing or coffer dam is sunk to keep out the sand and water from falling in. To avoid this difficulty, the most common type of pier for forest bridges consists of single row of 30 cm (one foot) diameter posts driven into the ground and provided with capsill beams fitted at the required height as in the case of abutment posts, Fig.103. The piles should be strengthened by ledger and diagonal bracings. In the case of a hill stream with a strong current where heavy floods are expected, an additional strut should be provided on the down stream side of the pier, as shown in dotted line. The piles should be driven down to firm foundations below the scouring depth of the stream.

4. Single Trestle Piers:-- Where the bed of the stream is of rock or other stable soil like gravel, the piers may be formed of framed structures called trestles, instead of pile-driven posts. The erection of trestles is much quicker and easier than pile-driving, and hence these are frequently used for temporary bridges. A good foundation is, however, absolutely necessary and they are not advisable where there is a strong current of water.

The trestle should be strong enough to bear the load, and should be strengthened by splaying the outer legs and by diagonal bracings spiked or bolted to the frame. The road-bearers should be securely fastened to the capsills to prevent any longitudinal swavinb of the trestles; in addition, longitudinal bracings should be provided between the single trestles, Fig.106, to prevent a collapse of the bridge. The outer posts should be given a batter of 6 in 1, and a ground sill or ledger connects the bottoms of all the posts, to spread the load uniformly over the ground and prevent sinking of the pier. In rocky ground, this ledger should clear the bed by at least 25 cm (10") to prevent it breaking, but in soft beds; special mud-sills may be provided below the ground sill. Fig.104 and 105 show a round span trestle and a more permanent framed single bent trestle respectively.

For heavy bridges, the piers are sometimes formed of two single trestles, braced closely together when they are known as Trestle towers or Double Bent trestle Fig.107. This gives greater stability and strength than a single trestle, and also greater width at top is available for resting the road-bearers. But it requires more labour and timber and is more difficult to construct and erect in position.

5. Crib Piers:-- A timber-crib is a frame work of logs of the shape and size required for the particular work. The ground is first levelled and one line of logs is first placed on it; the next layer of logs is then placed on these at right angles and spiked or trenailed to the logs below. This process is repeated till the necessary height, size and shape are obtained see Fig.108.

Crib piers are generally used for dry ravines or other places where there is no great danger from floods and floating timber, and also for temporary bridges. They may be made of rejected railway-sleepers or of round timber as shown in Fig. 108. Whenever a log is spiked cross-wise on another, the timbers must be notched or flattened to increase the bearing surface of each log and to prevent shaking or rolling. The base of the crib-work should be sunk well into the bed of the stream and a rough tray made across the bottom; the whole crib is then filled with large stores to prevent its being floated away.

Crib piers should not be used for heights of more than 3 m (10 feet) except in special circumstances, as in the case of a diversion bridge during the time required for repairing a breach in a permanent bridge. The length of the bridge pier should not be less than one and a half times the width of the roadway.

Appendix 4 gives details of design for a crib pier.

6. Road Galleries:- It often happens that a road has to be carried along the face of an almost vertical rocky cliff, where a trussed gallery would become necessary. If ab is the surface of the cliff, Fig.100 to be negotiated, cantilever trusses formed of horizontal beams cd supported by struts e and f, and strengthened by a diagonal strut g are used. The road bearer h span the cantilever trusses (suitably spaced along the cliff) and carry the decking i. Longitudinal bracing j between the trusses strengthens the whole structure. The truss, in addition to bearing on the cliff at c, rests on a wooden block, k, supported by an iron road driven into the cliff and screwed to the longitudinal bracing j as shown in the figure.

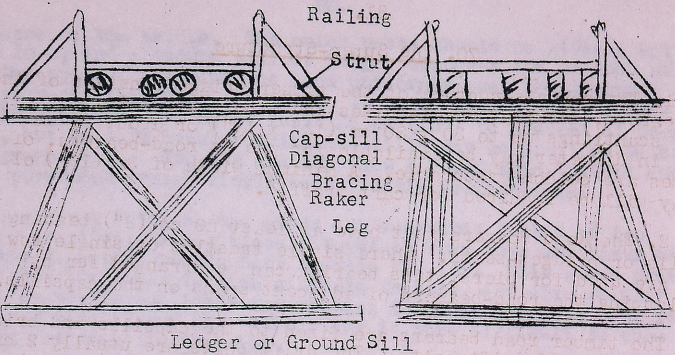

Railing
Strut
Cap-sill
Diagonal Bracing
Raker
Leg
Ledger or Ground Sill

Fig. 104 ROUND SPAR TRESTLE Fig. 105 SINGLE BENT TRESTLE

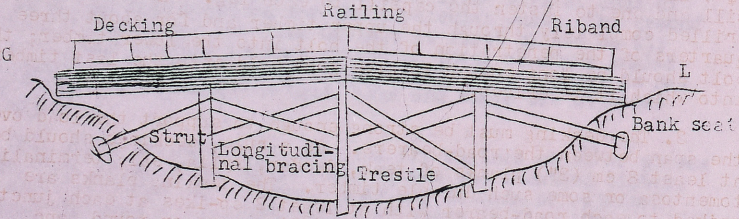
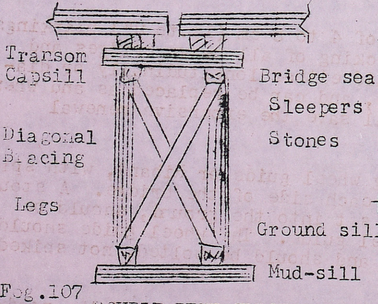

Railing
Decking
Riband
G
L
Bank seat
Strut
Longitudinal bracing
Trestle

Fig.106 SINGLE BENT TRESTLE BRIDGE


Transom
Capsill
Bridge seat
Sleepers
Stones
Diagonal Bracing
Legs
Ground sill
Mud-sill

Fog.107 DOUBLE BENT TRESTLE

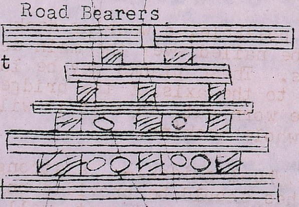

Road Bearers

Fig. 108 CRIB PIER

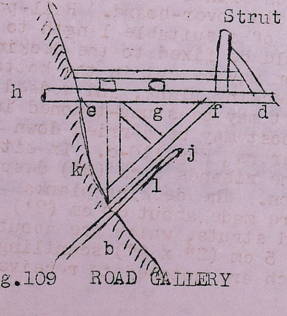

Strut
h
e
g
f
d
j
k
l
b

Fig.109 ROAD GALLERY

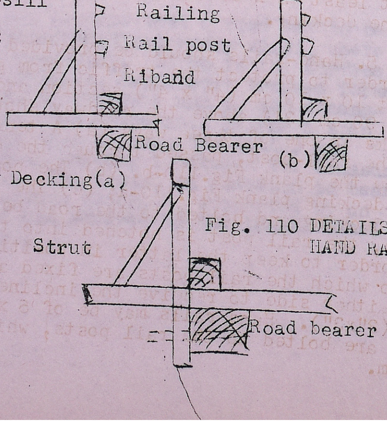

Railing
Rail post
Riband
Road Bearer
(b)
Decking(a)
Strut
Road bearer

Fig. 110 DETAILS OF HAND RAILS

70. The Super-Structure

1. The super-structure of the timber bridge consists of the road-bearers, decking, wheel-guides and hand rails, etc. Timber scantlings up to 30 x 30 cm (12" x 12") or about 38 cm (15"), in diameter may be available for use as road-bearers, of outsizes are seldom procurable. A minimum width of 3m (10') of roadway will be required for cart traffic.

2. The Road Bearers must have at least 20 cm (8") bearing on capsills or bridges-seats. Where single trestles or single row of piles are used for piers, this bearing can be arranged for by over-lapping the road-bearers of adjacent spans on the capsills.

The timber road bearers are fixed to the capsills and bridg-seats by means of drift bolts. The drift bolts are usually 2 cm. ($\frac{3}{4}$") in diameter, and two are used to fasten each leg to the bottom sill and one to fasten the capsill to each leg. The hole should be drilled completely through the upper timber and for about three quarters of the penetration of the bolt into the lower timber; the bolt should be long enough to give good hold into the last timber into which it is driven.

3. The decking must be strong enough to support the load over the span between the road-bearers. As a rule, deckings should be at least 8 cm (3") planks of teak, deodar, xylia, sal, terminalia tomentosa or some such durable timber. The decking planks are spiked to each road-bearer with at least 2 sp-ikes at each junction. The spikes are generally about 1 cm ($\frac{3}{8}$") square or round, and should be about 20 cm (8") long.

If possible, a wearing deck of 4 to 5 cm (1½ to 2") plankings should be nailed over the main decking of all heavy bridges and culverts. These planks may be laid either longitudinally or diagonally to the axis of the bridge, and can be replaced as and when they are worn out, so that it will save the expensive renewal of the whole decking.

4. Wheel guides:-- A strong wheel guide or Riband, with splayed approaches should be provided on each side of the bridge. A stout bumping post or guard post, well set into the ground, should be provided at each end of each wheel guide. The wheel guide should be at least 12 x 12 cm (5" x 5") and should be bolted, not spiked to the decking.

5. Hand-rails should be provided on either side of the roadway in order to protect the traffic from going over-board. Rail-posts, about 10 x 10 cm (4" x 4") section and of a suitable length to project 90 cm (3') above the roadway should be fixed to the decking planks in one of three ways (a) A tenon may be cut in the bottom of the rail-post, passed through the decking plank, and wedged below the plank Fig.110-b. (b) The post may be stump-tenoned into the decking plank Fig.110-a; (c) The post may be carried down through the decking and bolted to the road bearers, Fig.110-c. In either case, the rail post is notched into the ribands 5 cm (2") deep in order to keep the latter in position. The decking planks into which the rail posts are fixed are made about 60 cm (2') longer on either side to receive the inclined struts, which are about 8 x 8 cm (3"x3"). Hand rails may be of 5 x 5 cm (2" x 3") scantlings, and are bolted to the rail posts, which are notched to receive them.

71. Trussed Girder Bridges

1. There are many forms and designs of trussed girders, the simplest being the King Post or King rod truss. They take a long time to construct, and require skilled carpenters and blacksmiths for their construction, and unless the joints are very carefully made and are of throughly seasoned timber, they will open up and give endless truble later. Such timber trusses are, therefore, not recommended for forest bridges in the tropics.

2. Generally, timber is used for the struts and compression members, and steel rods for the tension members. The depth of the girder is generally between 1/8 to 1/12th of the span.

3. The bridge may consist of two or more girders. For spans upto 15 m (50'), two girders are used as a rule, and four to six girders for spans over 15 m (50'). The two-girders bridges may be either through bridges or deck bridges, but bridges with more than two girders have to be deck bridges only.

SECTION 13: CANTILEVER AND SUSPENSION BRIDGES

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72. Cantilever Bridges

1. As explained earlier, a cantilever bridge essentially consists of two counterpoised or weighted arms, built out from the two abutments, on either side of the gap and supporting on their free ends the central portion of the road-way of the bridge. The abutments of such bridges are generally constructed of dry rubble, and their faces provided with a batter on all sides to increase stability and weight.

2. Advantages:- These can be used when the gap to be crossed is too wide for adoption of a simple or trussed girder bridge, and where the bed of the stream is unsuitable for the construction of piers. No scaffolding or centering is necessary, since the bridge can be built out from either side of the gap. The construction does not obstruct the water-way to any great extent as does a trussed deck span bridge.

3. Conditions of Stability:-- The load that can be carried by cantilever bridge depends upon:-

(a) The distance to which the arms project beyond the abutments, i.e., the length of the cantleter arms--greater the length, less will be the load that can be supported at their ends.

(b) The size of the beams used, and their transverse strength.

(c) The amount of counterpoise or balancing weight on the inner ends of the beams and the distance of its centre of gravity from the face of the abutment -- greater the load and its lever arm, greater will be the balancing moment and hence greater will be the load that can be carried by the bridge.

4. Principles of construction:-- For an economical section, the central road-bearers and the cantilever beams should all be subjected to the same intensity of stress. If all beams are of the same size and each road bearer is supported by one pair of cantilever beams, the stresses in the beams of the cantilever arms and road-bearers will be approximately equal, when the length of each cantilever arm is about one sixth to one seventh of the span between the abutments. Fig.89 shows the different parts of the cantilever bridge. The central road-bearers rest on the ends of cantilever beams and the end spans, are supported by the ends of cantilever beams and abutments on either side. Only one third of the length of the cantilever beams project beyond the abutments. The cantilever arms are connected together by wall-plates and transoms, so that they may act together and thus give lateral stability for the bridge; planks are also nailed to the tops of embeded portions of the cantilever beams to bring the entire load of abutments over them and to increase the stability of the whole bridge.

5. Strengthening of a cantilever bridge:-- The cantilever beams will have to be fortified and lengthened until the gap between their ends is reduced to suit the simple or trussed road bearers, which are to span that gap. Fig.111 shows an elevation of one such cantilever support. The total span L is the horizontal distance between the two abutments and the length of the top most cantilever beams should be one-sixth to one-seventh of span as explained before. The lengths of the supporting cantilevers, l_1, l_2 etc., should be made slightly less and less l_1, being slightly less than l_1, l_2 being a little less than l_1, and so on.

The end road-bearers are supported by struts which are connected together by additional transoms.

The structure can be made stronger if the number of beams in each tier is increased by one as we descend; thus, if there are two road bearers, there may be three beams in the top tier of cantilever, four in the second, five in third tier, and so on. The stresses in the cantilever beams will then be very much less and also the area of pressure on the abutment will be very much larger, and consequently the structure will be stronger. In such a case, there is no need to reduce the overhangs of the cantilevers as suggested, and over-hand of each tier may be equal to l.

6. When round logs are used for cantilever arms, the logs must be fitted with all but ends outermost. For, since the portion of the log embedded is greater than the over-hand, fixing the butt outermost gives a larger cross-section of log at the place where it leaves the abutment, and where the stress is the maximum.

7. The construction of cantilever bridges is however, cumbersome and wasteful of material. They are, therefore, seldom used, and a suspension bridge will usually be a better proposition when wire-ropes can be secured.

73. Common Suspension Bridges.

1. Suspension bridges are the most convenient type of bridges for light load for spans of 30 metres (100 feet) and upwards, where

the bottom of the gap does not afford facility for constructing piers, owing to the great depth or swift current. They are specially suitable in interior of forests where the transport of material is particularly difficult, and they are chiefly used for pedestrain, mule and jeep traffic.

As the stability of the bridge depends on its anchorages, the site should be carefully chosed with sound banks, and if possible, banks of same height.

2. The best material for cables are chains and steel wire-ropes. When several small ropes are used instead of a large one, care should be taken to stretch them all evenly.

3. The regulation of the dip of the main cables is of great practical difficulty, and it is impossible to take all the slack out of the turns of the anchorage. Differential tackles are the best means of dealing with adjustment of the cables.

The dip of the cables i.e., the depth of the cable at the centre of the span below the level of the top of the piers, generally varies from one-seventh to one-fortieth of the span. A deep curve causes less stress in the cable and does not require long anchorage, but the bridge will be slack and oscillate too much, thus giving a sense of insecurity; on the other hand, the less the dip, the stiffer will be the bridge, but it causes great stresses in the cables, and long anchorages will be required. The dip usually provided varies from one-tench to one-fifteenth of the span.

Due to stretch in the cables and to the taking up of slack when the bridge is loaded, the final dip increases considerably. The cables should, therefore, be adjusted originally to a smaller dip than that required finally, by an amount 1/5 to 1/10 of the required dip, according to the length of the cables.

4. Lateral Stability:- The greatest difficulty with a suspension bridge is want of stiffness with a concentrated load traversing the span. To overcome the tendency of a suspension bridge to sway, in the wind:—

(a) The cables must be pulled closer together at the centre of the span providing a wasting of 1/6 the dip and splayed out by at least $\frac{1}{3}$ of the dip after passing the tdwers.

(b) The transoms may be strengthened by providing diagonal cross-bracings, and every alternate transom may be tied to one bank or the other by means of guy-wires (wind ties).

(c) Deckings and wearing planks may be laid at 45° to the axis of the bridge.

5. Vertical Stability:— Suspension bridges have also a tendency to bounce when vehicles pass over them. This can be minimised.

(a) By fixing struts from the pier-footing to the point of suspension of the first transom. Also tie-roads may be provided from the point of suspension of some of the long suspenders to the succeeding transom.

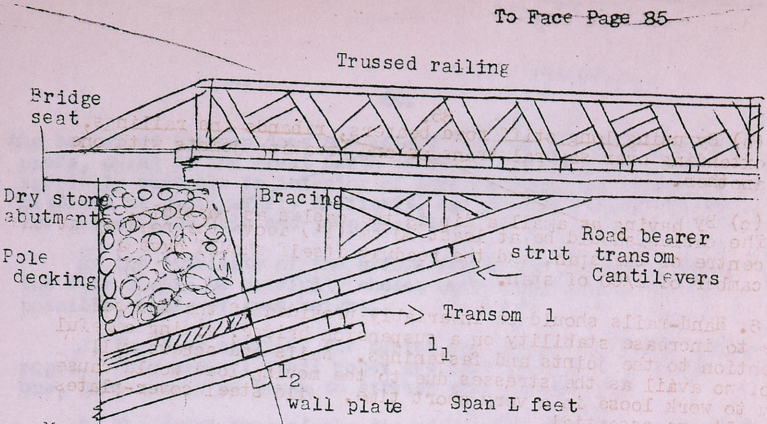

Trussed railing
Bridge seat
Dry stone abutment
Pole decking
Bracing
Road bearer transom
Cantilevers
strut
Transom 1
l_1
l_2
wall plate
Span L feet

Fig.111 3-Tier Cantilever Bridge

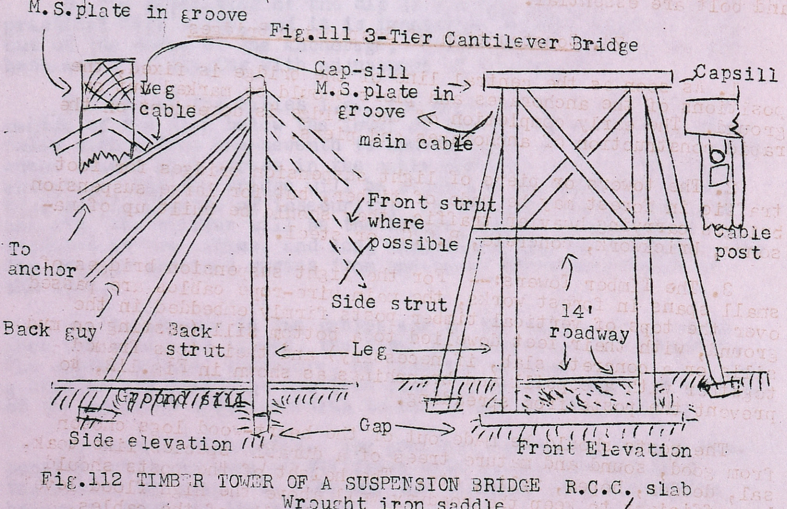

M.S.plate in groove
Leg cable
Cap-sill
M.S.plate in groove
main cable
Capsill
Front strut where possible
To anchor
Side strut
Cable post
14' roadway
Back guy
Back strut
Leg
Ground sill
Gap
Side elevation
Front Elevation

Fig.112 TIMBER TOWER OF A SUSPENSION BRIDGE

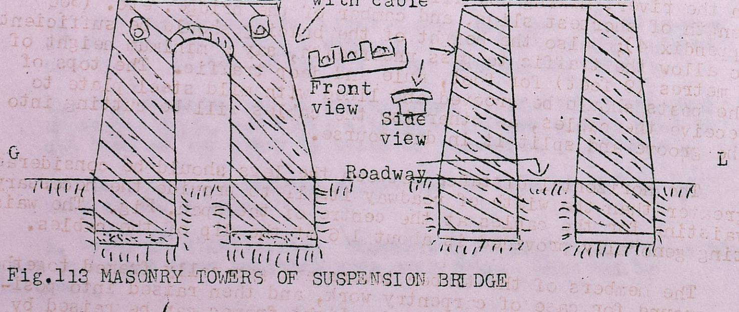

R.C.C. slab
Wrought iron saddle with cable
Front view
Side view
G
L
Roadway

Fig.113 MASONRY TOWERS OF SUSPENSION BRIDGE

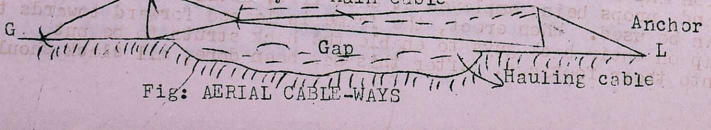

Sheer
Pulley
Main cable
G
Anchor
Gap
L
Hauling cable

Fig: AERIAL CABLE-WAYS

(b) By using long stiff road bearers, ribands and railings, extending over several transoms and breaking joints with one another.

(c) By having as amall a dip in the cables as possible. The cables should be at least 30 cm (1') above the roadway at the centre of the span, and the roadway itself should have a camber of 1/60 of span.

6. Hand-rails should be invariably provided of the trussed type to increase stability on a suspension bridge, giving careful attention to the joints and fastenings. Nails and screws will be of no avail as the stresses due to the moving load would cause them to work loose in a very short time. Mild steel cover-plates and bolt are essential.

74. Construction of Suspension Bridges

1. As soon as the central line of the bridge is fixed, the positions of the anchorages and piers should be marked out on ground. The early completion of the bridge is dependent on the rapid construction of anchorages and piers.

2. The towers or piers of light suspension bridges for foot traffic in forest may be made of timber, but for large suspension bridges carrying heavier traffic, they should be built up of masonry, brickwork, concrete, R.C.C. or steel.

3. The Timber Towers:-- For the light suspension bridges of small spans in forest works, the main wire-rope cables are passed over the tops of vertical timber posts firmly embedded in the ground, with their feet dowelied to a bottom sill (resting on mud sills or a concrete slab, if necessary) and their tops framed together with a capsill and branchings as shown in Fig.112, to prevent the posts from spreading.

The posts should be made out of the heart-wood logs chosen from good, sound and mature trees of a durable species like teak, sal, deoder, hopea, xylia, etc. The height of the posts should be sufficient to keep the roadway well above the high flood level in the river, making due allowance for the dip of the cables, length of shortest sling, and camber of the bridge, etc. (See Appendix 4); also the height of the bracing should be sufficient to allow the traffic to pass underneath, say a minimum height of 3 metres (9 feet) for foot, mule and jeep traffic. The tops of the posts should be grooved and lined with mild steel plate to receive the cables, as otherwise the cables will be cutting into the groove and split it in due course.

The horizontal distance between the legs should be considerably greater than the width of roadway itself to provide the necessary waisting for the cables at the centre of the span, Fig. The waisting generally provided is about 1/6 of the dip of the cables.

The members of the timber towers are generally framed together on ground for ease of carpentry work, and then raised into position and firmly fixed in ground. Light frames can be raised by hand, props being employed at each lift, until the back struts can be used. When erect, the frame is leaned forward towards the gap on their back guys to enable the back struts to be put into their footings. After this has been done, all slack should be taken out of the back guys and the guys secured to their anchors. When the piers are not close to the edges of the gap and space permits, it would be better to replace the back guys with fronts struts, as shown in dotted lines in Fig.112. The towers should then be supported by side struts to prevent swaying sideways.

For raising heavy frames, a single pole derrick may be employed particularly when steel towers are used in the case of larger span suspension bridges.

4. Masonry towers:- The masonry or concrete towers will be built in two parts with a gop in between for the passage of traffic. The top of the gap may be spanned either by an R.C.C. slab or a semi-circular arch, as shown in Fig.113. The height of the gap should be sufficient to allow the passage of traffic underneath about 5 m (16') for loaded trucks.

Rectangular or arched openings as shown are left near the top of the piers, and in them wrought iron saddles with necessary grooves for taking the main cables are fixed by means of foundation bolts.

5. When the working parties cannot cross the gap from bank to bank near the site of the suspension bridge, it always saves time to stretch as line across, as shown in Fig.114, with a pulley block to travel on it, for transporting materials and man quickly across the gap.

Appendix 6 gives details of design for a suitable aerial cable-way for the purpose.

6. The Anchorages:-- The stability of the whole bridge will depend upon the strength of the anchorages of the main cables, and buried anchorages will normally be required, though, for light loads, a good natural holdfast may sometimes be found in the shape of deep-rooted sound trees, if conveniently situated.

The strength of a buried anchorage will depend upon the strength of the log itself and also on the resistance of the ground to the pressure that will be brought upon it by the pull of the main cables. The minimum horizontal distance of the anchors from the pier footings should be 2.5 times their height, and distance from centre to centre of the anchors on each bank should be sufficient to allow for the splay of the cables from pier to anchorage, which is generally taken equal to $\frac{1}{3}$ the dip. The length of the log and the depth of trench will depend upon the holding power required, and an example of design is given in Appendix 5.

The simplest from of this anchorage consists of a single log burried horizontally in the ground with the cable taken round it as shown in Fig. 115. The face of the trench should be as nearly vertical as possible, and the length of the trench 50 cm (18") longer than the anchor log. The running end of the cable should be brought above the ground level through a narrow trench and made fast to standing end, so that it is under observation all the time. After the completion of the bridge, the trench may be filled in and rammed with earth and the roadway over the excavation completed. In the case of a permanent bridge, however, iron girders or R.C.C. beams with rails or girders encased in cement concrete, should be used for anchor logs. Fig.116 shows two forms of anchorages generally used.

7. The cables:- When the anchorages and the pier frames are ready, the cables are stretched across the gap, laid on either side of the position of the frames and taken round the anchorages. The bearings on the towers are well-greased before raising the cables.

Light cables of 8 cm (3") S.W.R. or smaller sizes can be raised by hand, but for larger cables tackles will have to be used. A double-treble or single-double tackle secured to the tip of two long poles may be used, the poles being lashed to the capsill of the tower. A long spun yarn Bridle (Fig.117) is secured to each cable in front and rear of where it should rest on the tower for providing the necessary unloaded dip and waisting, and the lower block of each tackle is hooked on to the bridle. A snatch Block is lashed to the leg of the tower to pass the running end of the fall to the rear. The cables are now raised and dropped their positions and cleared of the bridles.

As soon as the cables have been raised on to the first pier, the ends of the cable on that side of the gap should be made fast to the anchorages by taking a complete turn and securing the running end to the standing end by one of the following methods:-

(i) With three sets of bull-dog grips or double-throated clamps or shackles, as they are termed see Fig.116.

(ii) Seize the running end of the cable to the standing end with strong tarred spun yarn nearly up to the end; open out the strands, bend them back over the seizing and pass fresh seizing round so that they form a plug.

The cables are then raised on to the second pier, the slack taken in, with a man at each anchorage, easing round the turns, until the dip of the cables in the centre of the span is rather less than the final dip required; the dip can be ascertained by nailing horizontal reepers at the corresponding heights on the legs of the piers, and sighting the bottoms of the cable curves.

The other ends of the cables are also now secured to the standing ends, and the anchorage trenches are then filled in, and rammed. Alternatively a masonry chamber may be built around the anchorage and grooves to facilitate inspections--see (Fig.116-b).

Whenever wire-ropes are to be bent round sharp corners, like through the eye of a straining bolt, back-stay rod, or screw-coupling, etc., they should be passed round a mild steel thimble with a smooth curve, as shown in Fig.116 and 118, so that the wire-ropes may not snap under the heavy strain of stretching round a sharp curve.

8. Transoms:-- The transoms should be placed simultaneously from both ends of the span. A suitable traveller can be made by placing a light spar or pipe across the top of the cables, and suspending a plank from it, on which the men securing the transoms can sit; the lashing by which the plank is suspended should be attached to the spar or pipe outside the cables. Light tackles should be suspended from either end of the spar to allow of raising or lowering the transom as required. Ropes from both banks should be attached to the traveller for hauling it backwards and forwards.

9. The ~~transom is attached to the sling or suspender in one~~ of four ways:--

(a) By passing the wire-rope sling through a hole bored in the transom, opening out the strands and driving a wooden plug into the hold from below, as shown in Fig.118-a.

(b) By fixing an eye-bolt (or straining bolt) through the transom, and passing the lower end of the wire-rope sling through the eye of the bolt and securing it to the standing end by either bull dog grips or seizing; opening out the strands and re-seizing with tarred spun yarn, as shown fig. 118-b.

(c) By round turn and two half-hitches around a log transom and seizing at three places, as shown in Fig. 118-c.

(d) By passing the rod-suspender through the eye of the straining bolt and seizing Fig.118-b.

10. The upper ends of the suspenders or slings are connected to main cables at equal horizontal distances along the span by one of the following ways:-

(a) A round turn around the cable and three bull dog grips.
(b) A round turn around the cable, twisting the running end twice round the standing end, opening out the strands and twisting them all round and round, Fig.119-a.

(c) Wrought iron clamps, shaped to the size of the main cables and serrated on the inside to provide a good grip on the wire-rope cables are placed on the upper and lower sides of the cables and bolted securely, using an eye-bolt in the middle. The suspender or sling is passed through the eye of this central bolt and secured as in the case of the transom Fig.119-b.

In either case the suspenders or slings are prevented from slipping along the main cables, by making a strong collar of tarred spun yarn or by fixing bull dog grips on either side of their correct positions.

11. Adjustment of slings:- The length of the suspenders should be such that the road-way, when completed, should have a camber of 1/60 of span. The actual length of each suspender can be roughly obtained graphically, by first finding its vertical length from the elevation of the bridge and then its true length by plotting this vertical length and the splay at the particular position; (for the splay given to the cables in plan makes some suspenders more inclined to the vertical than others). In each case, remember to allow extra lengths required for fastening the suspender both to the main cable and to the transom.

In usuage, it is possible, that some of the slings stretch and thereby cause a slackness in the cables and attachment. Hence, it would be very useful to provide some arrangement by which the slings can be tightened up, without having to dismantle all the transoms and roadway. A screw-coupling is one such arrangement, consisting of a rod A with screw-threads cut in opposite directions

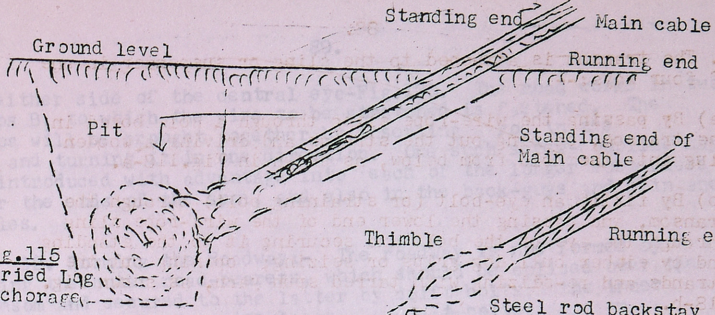

Standing end
Main cable
Ground level
Running end
Pit

Fig.115
Brried Log
Anchorage

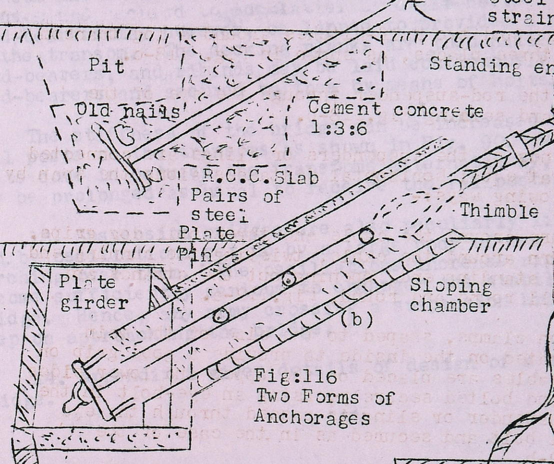

Standing end of
Main cable
Thimble
Running end
Steel rod backstay
straining bolt
Pit
Standing end
Running end
Old nails
Cement concrete
1:3:6
Bull-dog-Grip
R.C.C.Slab
Pairs of
steel
Plate
Thimble
G
Pin
Plate
girder
Sloping
chamber
(b)

Fig:116
Two Forms of
Anchorages

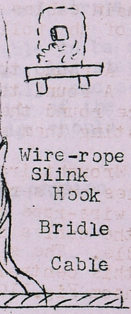

Wire-rope
Slink
Hook
Bridle
Cable

Fig: 117 Spun Yarn Bridle

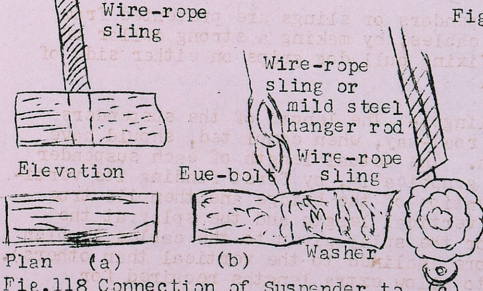
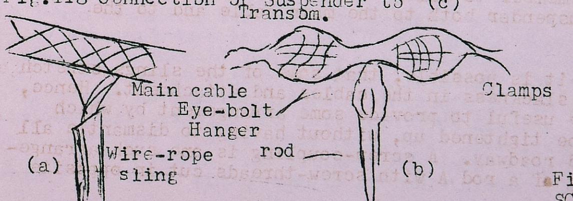

Wire-rope
sling
Wire-rope
sling or
mild steel
hanger rod
Wire-rope
sling
Elevation
Eue-bolt
Washer
Plan
(a)
(b)
(c)

Fig.118 Connection of Suspender to Transom.


Main cable
Clamps
Eye-bolt
Hanger
rod
Wire-rope
sling
(a)
(b)

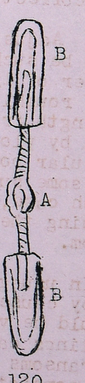


Fig: 120
SCREW COUPLINGS

Fig: 119 CONNECTION OF SUSPENDERS TO CABLES.

on either side of the central eye-Fig.120. The road works in two loops B, to which the wire to be stretched is fastened. The loops will be brought together by inserting a rod in the eye and turning it in one direction. One such screw-coupling may be introduced with advantage into each of the longer suspenders near the ends of the span, and also in the back-guys and main anchor cables.

12. Forming the Roadway:- The roadway is now formed by adding the outer road-bearers, which should be spliced over the transom and secured to the latter by drift bolts; the inner ~~transom and secured to the latter by drift bolts; the inner~~ road-bearers may however, be lapped to provided a proper bearing on the transom. The decking planks are then nailed down on the road-bearers, and ribands may be laid continuously over the outer road-bearers and secured to them by means of bolts.

The stiffness of the bridge can be increased by fixing the rail posts to the transoms as shown in Fig. 90. When the rails-posts come in between the transfoms alternatively, the decking planks may be prolonged as usual to receive the railposts and struts.

13. Suspension bridges are also peculiarly liable to be strained by oscillations set up by a large body of men keeping step while marching over them. The oscillations increase rapidly, and soon become sufficiently serious to endanger the stability of the bridge. Hence, any army crossing a suspension bridge should break step on approaching the bridge.

14. Appendix 5 gives details of design of a suspension bridge.

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PART V -- WATER SUPPLY

SECTION 14: GENERAL

75. Introduction

1. Importance of ensuring the purity of the water to be supplied for public consumption is self evident. The normal sources of supply may be wells, springs, streams, lakes or reservoirs. For a majority of forest villages, the source of water has always been wells, through some areas are often traversed by streams or rivers in other areas the waters coming down in torrents during the monsoons are impounded in reservoirs by putting in earthersn bunds or masonry walls across them, and this water is made available for consumption to the community throughout the year.

2. The well being the commonest source of water, the question of providing clean well s of a vital importance to the health of the forest community, Unless properly constricted and well protected,the well may become the source of untelling danger to the community as a whole, since water is the principal medium by which pathogenic bacteria causing epidemic diseases lime cholera, typhoid and dysentry, etc, enter the human bodies. Utmost care should, therefore, be taken in selecting a site for a well, and the well should be lined with some infectious proof material.

3. The requirements of a safe water, for domestic consumption may be summarised as follows:-

(a) A safe water should, as far as possible, be free from colour, odour and taste.
(b) It should contain no appreciable amount of mineral or organic suspended impurities.
(c) It should be neither too hard nor too soft.
(d) It should not contain large quantities of common salt or alkaline carbonates.
(e) It should be absolutely free from poisonous substances, either organic or inorganic.
(f) It must not contain any pathogenic, i.e., disease-producing bacteria of any kind.

4. The only natural waters which satisfy these minimum requirements are upland surface waters (the catchment areas of which do not include cultivated lands or dwelling), deep wells, artesian wells, springs, and rain-water collected before reaching the ground in country districts. Even in such cases, before the water is supplied for drinking purposes without purification, the area should be carefully inspected to ensure that there is no possibility of pollution, and the water should be carefully analysed, if possible, after a spell of dry weather and also after heavy rains.

5. Practically all other sources of water are liable to contamination with sewage or surface drainage, and some form of purification is necessary before the water can be considered safe for human consumption. The most dangerous agents causing pollution of water or thepathogenic bacteria persent in the excreta of men and animals suffering from the diseases like Cholera, Typhoid and Dysentry, etc. The water infected with bacterial cannot be distinguished from pure water by mere appearance, odour or taste, and therein lies the danger; only a careful chemical and

bacteriological analysis will show their presence and nature.

6. The waters in the streams and rivers get contaminated by human exereta, when a hamlet is situated near their banks, but running water purifies itself by constant exposure to sun and wind, etc., during its flow. The well-water gets contaminated by seepage of sewage, inflow of surface drainage, and by droppings of birds, etc., and hence precautions should be taken to prevent the contamination.

76. Sources of water

1. Hydrology:- The original source of all supplies of fresh water is either rainfall or snowfall. Rain is caused by sudden condemsation of water which has been raised by evaporation from the surface of the seas and to some extent from the surfaces of water on land. In cold regions like the himalayas, the snow collects during winter and the cold seasons, and this melts during the hot seasons and flows down the slopes in the form of rivers, etc.

Part of the water which falls as rain runs out as surface water into the streams and rivers, which again empty into the sea, a portion is directly evaporated into the atmosphere, a part is absorbed by the vegetation on the soil, and a part sinks into the ground either directly where it falls, or by gradually sinking in from the beds of streams and rivers or pools and lakes. Some of the water which sinks, into the ground is absorbed by the soil or mass of rock it passes through, and is subsequently either absorbed by vegetation or is evaporated. But a large portion of the underground water normally continues to descent until stopped by strata or layers impermeable to water. The rate of flow of this under ground water is usually very slow, due to the resistance offered by the particles of soil.

2. Streams and rivers:- Water from stream with upcountry catchment areas, which are uninhabited and uncultivated with rocky surface, is generally safe for all practical uses; but if there are any villages near the stream, it will nearly always be contaminated due to the common custom of people using the banks of a neighbouring stream as latrines. A forest village should therefore be sited upstream from a village, whenever possible. Running water is however, found to purify itself by flowing for a considerable distance, the distance, being dependent on the volume of water and the extent of contamination.

Stream or river water is particularly dangerous at the beginning of the rains and during a flood, as the stream then brings down all the contaminated surface deposits on the banks; the water used for drinking should then be invariably boiled and cooled to kill all the pathogenic bacteria, if any.

When using water from shallow stream or from small streams in the dry weather, it is best to dig a shallow well, about a metre (2 or 3') below the bed level of the stream near its bank and draw water from the well. Since the water then has percolated through the soil, it has filtered itself and is usually safe for domestic use.

3. Ponds and Lakes:-- Stagnant water in a small pond is always dangerous and should never be used for drinking purposes. Large lakes in the uninhabited mountainous country, on the other hand, may be quite safe for human consumption but water from these lakes should be used only after a careful chemical and bacteriological analysis.

4. Springs:-- The earth's crust consists of a series of layers or strata of different kinds and of varying thickness, as can be observed in a deep earth cutting. Some of these strata contain sufficient voids and openings to allow water to flow slowly through them, and these are known as Permeable strata, such as sand, gravels, and large masses of chalk, etc. Other types of strata, which consist generally of clay or hard rock do not allow the passage of water through them, and these are termed Impermeable strata.

The rain water falling on a porous or permeable surface stratum, percolates downwards until it meets an underlying impermeable stratum, over which it starts accumulating, and slowly flow laterally. If, during the course of the slow movement of this underground water, it meets the surface of the ground, it emerges in the form of a spring, Fig.121.

Spring water is nearly always wholesome and uncontaminated, owing to the thorough filtration it has undergone inpassing through a considerable thickness of porous soil before issuing as a spring. It might, however, contain salts or sulphur and calcium compounds from the rocks through which it has passed, and therefore the water should be analysed before use. To guard against the pollution of spring waters, it is desirable that the point of delivery be walled in, and the water conducted to the surface by means of a pipe.

5. Wells:- Wells may be divided into three types, Shallow wells, Fig.122, Deep wells, Fig.123, and Tube wells, Fig.128.

6. Shallow wells are wells sunk into superficial permeable beds overlying an impermeable stratum as shown in Fig.122, and obtain their water from rainfall in the vicinity. The water in these shallow, surface wells is open to much pollution, owing to the surface drainage and sewage soaking into the ground, gradually finding its way into these surface wells.

7. Deep wells are those wells which are sunk through at least one impermeable stratum into a water-bearing permeable stratum as seen in Fig.123. Since water in these deep wells has been filtered through a thick layer of soil, it will usually be of good quality, and if the well be sunk several feet below the water level, the yield may be considerable. Thus deep wells and bore wells offer a means of tapping the deeper waters with the aid of pumping machinery, when the type of soil is suitable. The superficial polluted waters are cased off by the intervening impermeable stratum and the surface inflow can be prevented by lining the wells from the first impermeable stratum upto to a few feet above ground level.

8. A bore-well is similar to a deep well, but narrow and deeper, since it may have to be carried through more than one impermeable stratum to reach the underground water-bearing stratum.

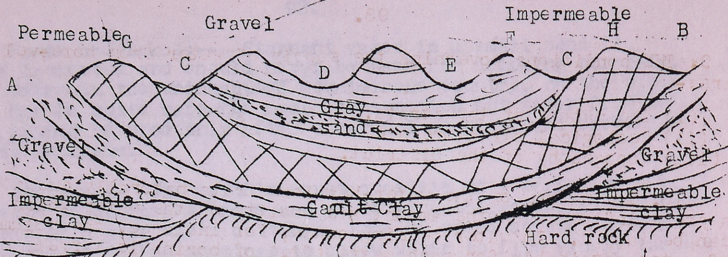
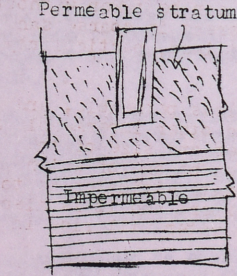

Permeable
G
Gravel
C
D
E
Impermeable
F
H
B
C
A
Clay
sand
Gravel
Gravel
Impermeable clay
Gault Clay
Impermeable clay
Hard rock

Fig.121 SECTION OF A TYPICAL BASIN


Permeable stratum
Impermeable

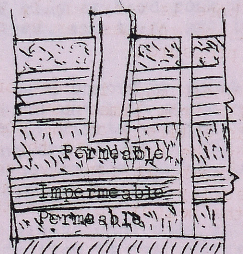

Permeable
Impermeable
Permeable

Fig:122 SHALLOW WELL Fig: 123 DEEP WELL BORE WELL

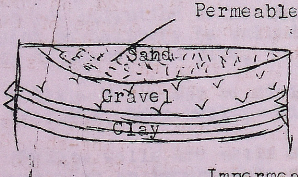

Permeable stratum
Sand
Gravel
Clay

Fig: 124 SYYCLINAL AXIS

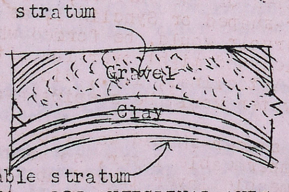

Gravel
Clay
Impermeable stratum

Fig: 125 ANTICLINAL AXIS

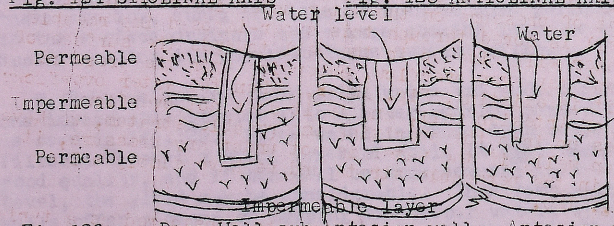
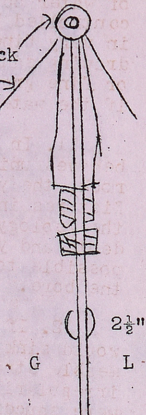

Water level
Water
Permeable
Impermeable
Permeable
Impermeable layer

Fig:126 Deep Well sub-artesian well. Artesian well
ARTESIAN & SUB-ABTESIAN WELLS


Double sheave
Pulley block
Ropes
Monkey
Driving
clamp
Socket
$2\frac{1}{2}$"
G
L
$1\frac{1}{4}$" tube well
1'9"

Boring Bit

Fig: 128 TUBE WELL

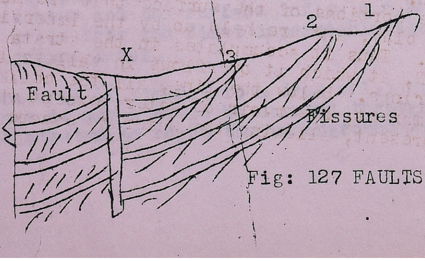

1
2
X
3
Fault
Fissures

Fig: 127 FAULTS IN ROCKS

9. THE conditions governing the supply of water from bore-well are:-

(i) The nature of the strata,
(ii) Geological structure and
(iii) Topography of the District.

10. The nature of the water-bearing strata naturally exercises a great influence on the amount and quality of the water which can be tapped. In water bearing sands, for instance, the volume of water obtainable for each metre (ft.) of boring is largely controlled by the rate at which water can flow through the sand; in very fine sand, the volume of water which can be taken without drawing sand into the bore is very small, whereas in coarse sand or fine gravel, very large volumes can be obtained, particularly if the water is under pressure.

11. In chalk, the whole mass is more or less permeable, and behaves uniformly, while from limesstones and other impermeable hard rock, the yield depends entirely on the number and size of the fistures intercepted by the bore. If the area be one of which the geology is fairly known, reasonably accurate estimates as to depth and yield can usually be given by an expert and it is also possible to forecast the height to which the water will rise in the bore.

12. If all the strata at the surface were horizontal, water would sink through the permeable layer and would lie over the impermeable stratum below, and ooze out at any out-crop formed by the irregularities of the surface, e.g., on a hill side., If the strata were saucer-shaped or Synclinal, as shown in Fig. 124, an underground reservoir would, be formed which would in course of time, become filled and might overflow after heavy rains. If the strata are Anticlinal, i.e., dipping away from the place as in Fig. 125, water would be seeping away underground.

If the saucer-shaped water-bearing stratum is again covered up by an impermeable layer, so as to leave only a ring-shaped area of the permeable layer locked up, the water collected in the basin will rise only in the area of the ring itself, thus causing a certain amount of pressure on the water under impermeable stratum. If a well is bored through this super-imposed impermeable layer, the water will rise up in the well towards the surface of the ground, and may even overflow, depending upon the pressure under which it is existing, Fig. 126-b, When the water overflows, it is termed an Artesian well, and if it does not overflow but only comes up into the overlying impermeable stratum, we have a Sub-artesian well; if the water is not under any pressure, it just remains in the permeable strata and we have simply a Deep well, see Fig. 126.

13. As an illustration, Fig. 121 may be considered as a typical section of a basin. Water in all the strata is derived from rain which falls on the portions of the surface that are not covered by the impervious clay, and are held up by the impervious clay beds of the gault. Thus it accumulates in the strata up to the horizontal line AB, at which it overflows in valleys like C, in the form of springs. Below the line, all the chalk, etc., are filled with a permanent, reservoir of water, except when faults or fissures are present, allowing the water to escape into the

lower layers. Otherwise, AB gives the level upto which water will rise in any well when the overlying clay is bored through. If the surface of the ground is below the line AB, the water will rise in a perpetually flowing Artesian fountain as at D and E, without any pumping whereas a well bored at F will only give a sub-artesian well. A well dug in the surface permeable soil at G would give a shallow well; and that at H, a deep well.

14. Faults in geological strata affect this question in various ways. Suppose Fig.127 represents the section of a portion of a basin intercepted by a fault AB filled with clay. 1,2,3 are porous strata, the remaining ground being impervious. Rain-water failling on the porous strata 1,2,3 and also that falling over the intervening impermeable portions, 1,2 and 2-3, will be held up by the fault acting as a dam. A well sunk at X will yield water which will rise to a greater height and in greater volume as each successive layers of strata 1,2,3 are tapped.

15. Tube Well:-- These are specially useful in sandy beds of streams, when water level has sunk too low to be reached by other means. The tube well consists of a tube with perforations at the lower end, and driven from the surface to the water bearing stratum, Fig.128. A pump may be fitted to the top of the tube, but is not, strictly speaking, a part of the well.

The tube, being small, is, in itself, capable of containing only a very small supply of water, which would exhausted by a few strokes of the pump. Therefore a tube well can be effective only when there is free flow of water from the outside through the appretures into the lower end of the tube. When the waterbearing stratum consists of gravel or chalk, water flows in freely and the yield may be as great and rapid as the pump can lift; in fine sand or sandy loam, the yield may not be great at the beginning, but the effect of constant pumping is to draw up with the water, a good deal of the find sand and clay, thus creating a hollow round the foot of the tube, forming a reservoir of water, and hence yield will improve; in dense clays, however, the tube well is not applicable, since the perforations at the bottom get choked and water cannot enter the tube, while the well cannot itself be driven through hard rock or in soil mixed with large stones.

77. The Water Table

1. Rain water falling on permeable stratum percolates slowly downwards until it is stopped by impermeable stratum, and then starts accumulating in the basin until it finds its own level, saturating the soil. The level of the surface of this underground water is called the Water table. In shallow permeable stratum, the water table may rise to very near the surface of ground, and give rise to water-logged areas or marshy places.

The level of this water table depends upon the topography, geological structure and the climate of the place.

2. Topography :-- The water table rises and falls following the general undulations of the country, but with smaller variations. It is deepest under high peaks and nearer to surface in regions drained by deep valleys.

3. Geological structure:-- Water table exists nearer the surface in fine textured soil than in coarse woil, and nearer under open grass fields than under forests. The inclination of the water table is also modified by the difference in the soil texture, character and position of the underlying rocks, and by the presence or otherwise of vegetations in the area.

4. Climate:-- The water table rises up after wet weather and falls after droughts and dry weather. Naturally when the surface is cold, the water rises up to the surface by capillary action to release the surface tension caused by cold.

SECTION 15: SINKING OF WELLS

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78. Shallow Wells

1. Selection of site:-- When prospecting for water, the following indications may be helpful:

(i) Water is more likely to be found where grass remains green or more verdant in one place than the other during the hot weather;

(ii) In summer, insects hover over damp spots, and remain in columns above the site of underground springs;

(iii) Denser vapours rise from those portions of the surface below which springs exist, especially early in the mornings and late in the evenings;

(iv) Springs are often to be found at the junction of a transverse valley with the principal one.

However, as previously indicated, the water from a shallow well is very much liable to be contaminated, and it should, therefore, be never sunk near latrines, cattle sheds, burial grounds, stagnant pools, or other sources of contamination; nor should it be sunk too near a road, the dust ffom which may pollute the water. A well should usually be sited at a low level to reduce the depth of surface drainage away from the well.

2. Depth of well:-- The depth to which a well may have to be sunk to obtain the necessary amount of water supply may sometimes be indicated by comparing the depths of existing wells in the locality, or by a careful study of the geological structure of the strata at the place an expert's job. A well sunk near the banks of a sluggish stream will often reach a permanent supply of water at a depth only a little below the low-water level of the stream.

3. Excavation:. Wells should always be dug in the hot weather when the water level is at its lowest. The method of excavation will naturally depend upon the nature of the soil. If the soil is stiff enough, as in gravel or hard clay, the excavation may be carried down vertically till the full depth is reached.

4. In the case of a temporary well, which is required for a

short duration only, all that is necessary is to dig a shaft of diameter that will allow of the men excavating it work efficiently, and of sufficient depth to yield the quantity of water required for the daily consumption. If the soil is sufficiently stiff, no lining is necessary, but if the soil is not stable, the cheapest lining procurable--timber or wattling (twisted brushwood)-- may be used.

5. When the well is required to be in permanent use, it should be carefully lined so as to keep the sides from falling in, and to prevent any surface drainage from entering the well and pulluting the water. The lining for a well is called Steining and may be of masonry or brickwork, Earthenware rings, cement concrete, or timber. The diameter of the well depends upon the amount of water required for daily consumption, and the rate at which the well can refill itself.

If the soil is stiff enough, the excavation can be carried down to the required depth, and of diameter at least 60 cm (2') more than that of the finished well required, and then the steining commenced from the bottom. Otherwise one of the methods of sinking described below may be used. When wells are excavated in hard ground and no lining is required to hold up the soil, a steining should be provided for a depth upto the first impermeable layer to prevent pollution from surface drainage.

79. Steining

1. The form of steining used depends upon the character of the soil through which the well is dug. When timber steining is used, it tends to rot rapidly, and often causes discoloration of water. Hence, it is normally used only for temporary wells; also it cannot be made water-tight. Steining in normal use is generally of masonry or brickwork.

2. Timber-lines well:-- Wells lined with timber are usually made square in plan, and generally about 1.2 to 1.5 m (4 ft.), square and not more than 2 m (6) feet square, since larger sizes need strutting and cross-bracing. The timbering consists of

(i) Square frames called settings, which are made up of 4 beams called sills; Fig. 129, laid horizontally and kept apart by vertical props, b.

(ii) A walling c of 5 to 8 cm (2 to 3") thick boards behind the settings.

The settings are usually of sized timber 15 to 20 cm (6 to 12") square kept about 2 m (6 ft) apart by props about 10 to 25 cm (4 to 9") sq. which are fixed to the sills by 15 cm (6") spikes.

3. In hard soil, the shaft may be dug to its full depth, and the timber steining built up from the bottom. The space between the steining and the sides of the excavation is then filled up with puddle (well kneaded clay) to make the steining water-tight.

4. In unstable soil, Fig.129, the method of under-pinning is adopted. Dig the shaft upto a depth which will stand by itself, and build up the timber steining. Dig a small pit e about 2 m (6 ft) deep in the centre of theshaft and at the bottom of this pit place a wooden block about 25 cm (9 inches) thick with bevelled edges, called a foot-block, f. Cut deep notches through the sides of this pit, and intorudce inclined wooden props, raking props, g, into them the lower ends of these props rest against the foot block, while their upper ends support the lowest setting of the steining above. Now enlarge the pit to the size of the shaft above and construct another setting and props, i.e., extend the steining. Place the walling boards in position and remove the raking props. The above operations may be repeated until the required depth is reached.

The timber generally used for steinings should be durable hardwoods like pine, deodar, sal, mango, jaman, etc.

5. Masonry or brickwork steining:- The thickness of the steining to be provided depends upon the nature of the strata, the diameter of the well and its depth. Small wells upto 1.5 m (5') diameter may be lined with 10 cm (4½") brick-work while those above 1.5 m (5') diameter are lined with at least 20 cm (9") brick wall.

Depth of steining	Brick-work steining	Masonry steining
For wells under 3m (10') depth	30 cm (13½")	30 cm (12")
For wells between 3 and 10 m (10' and 33') depth	40 cm (18")	40 cm (15")
For every additional 3 m (8') depth add	10 cm(3") and	10cm (3")

Brickwork is generally laid dry for several courses followed by three or four courses laid in cement mortar, unless water is to be excluded, when the whole work may be laid in cement mortar.

6. Wells line with masonry or brickwork are usually cylindrical in form, always so when the well is to be sunk through soft strata, but they may be square or rectangular when the soil is hard enough to allow of complete excavation before building up the steining. The space between the face of the excavation and the steining should be filled with well-puddled clay to prevent any infiltration of sewage or surface-drainage into the well. The brickwork, in the steining is generally pointed on the cement mortar, but 5 cm (2") thick lime-mortar plastering on the back of the steining gives a better protection against infiltration.

7. The steining may be sunk in three ways, by weighting, by hanging up the steining in stages, and by under-pinning.

8. But weighting:-- First a pit is dug, either with vertical or sloping sides, as deep as the soil can stand. Then a well-curb (an iron-shod timber ring, Fig.130) is placed at the bottom of the pit in a perfectly horizontal position.

A well-curb consists of a flat ring made either of timber or iron, having a slightly larger external diameter than that of the well steining to be constructed. The upper surface of the well-curb is flat, and on it the brick or stone lining will be built; The lower surface of the curb is bevelled and shod with mild steel plates to form a sharp cutting edge to facilitate sinking of the well. The timber generally used forewell-curbs are banyan, pipal, mango, sal, deodar, chir, semal and jaman.

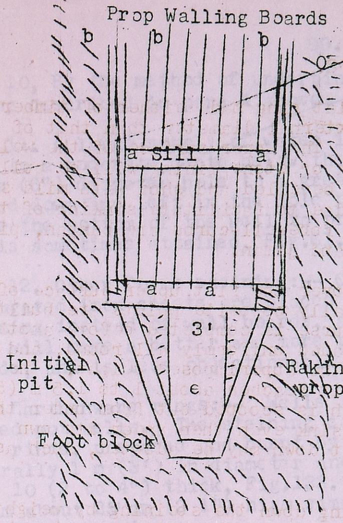
The steining is then built over the flat upper surface of the curb, taking care that diametrically opposite points are built up simultaneously, and that each course is completed before another is begun, so that the curb is loaded uniformly all round, and the well sinks truely vertically by the superimposed weight. The steining is thus built up until it reaches about 1 to 1.5 m (5') above ground level, and the earth is scooped out from under the curb. If the steining does not sink even then under its own weight, some method of forcing it down may be adopted, such as by weights or jack power.

One of the methods of forcing down the steining by weights is shown in Fig. 131. The well is fitted with an iron cap A, which has angle-iron flanges of a size that will admit of four ring bolts, a, of large diameter passing from a staging C, supported on piles or other secure foundation. +The frame B is commected with the staging C by means of bolts b, b, and is heavily loaded with weights W (old rails or girders). But turning nuts, d, d, the weights can be transferred either to the staging C or to the cap A. Thus the sinking of the cylinder can be adjusted, and as the actual weights used need not be much above the ground level, the accidents are minimised.

To know whether the steining is sinking vertically or not, four plumbs are hung up at the quadrant points close to the steining. All the plumb bobs should be touching the [illegible] lining, and if one of them is swinging away, it means that the steining is leaning to the opposite side, and the weights should be shifted suitably to bring back the steining to the vertical.

To secure the curb to the masonry and to prevent the lower part of the steining getting detached during the sinking, six 3 cm (1") diameter vertical tie-rods are built in through the steining, secured with washers at their lower ends and a circular iron ring 10 x 1 cm (4" x ½") at their tops, see Fig.140.

9. In the case of very deep wells, if the steining does not sink by loading on top, the steining can then be built in sections. The top steining is sunk as far as possible by loading on top and under-cutting below the well-curb. Then this steining is hung up by means of mild steel tie-rods bolted to R.S.J. s supported on crib-work on opposite sides of the well, and bolted to beams connected to the well-curb below, as shown in Fig. 132. Then a separate well-curb is assembled below the first steining, and sinking then proceeds as before, as far as possible, the second vertical section is then hung up from the first curb, as shown in Fig. 132, and so on. If the steining cannot be sunk even like this, a well-curb of smaller diameter than the previous curb above is placed and a smaller steining built up on this, resulting in a stepped steining as shown in Fig.132. Care must be taken to see that there is proper bonding of brickwork or masonry.


Prop Walling Boards
b
b
b
a Sill a
a
a
3'
e
Initial pit
Raking prop
Foot block

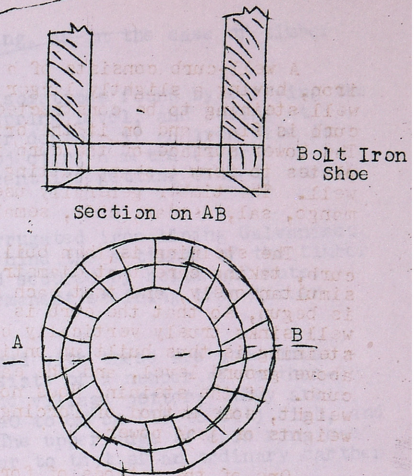

Bolt Iron Shoe
Section on AB
A
B

Fig.130 THE WELL CURB

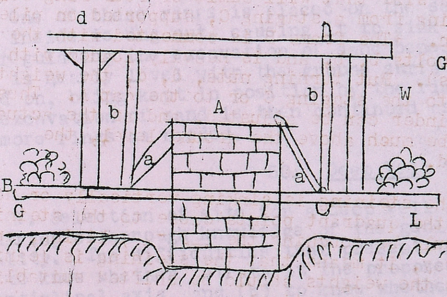

d
b
b
A
W
a
a
B
G
L

Fig: 131 FORCING DOWN A STENING

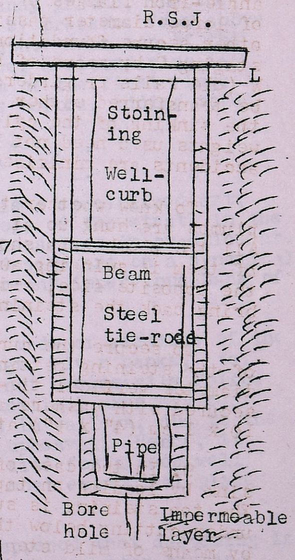

R.S.J.
G
L
Stoining
Well-curb
Beam
Steel tie-rode
Pipe
Bore hole
Impermeable layer

Fig: 132 STEPPED STENING

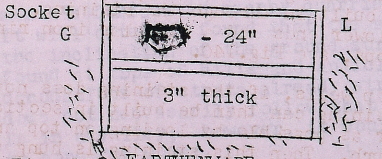

Socket
G
L
- 24"
3" thick

Fig: 133 EARTHENWARE STEININGS

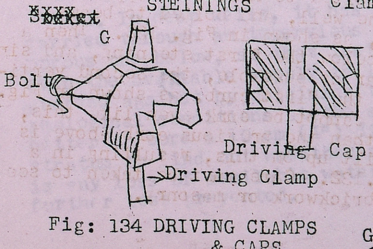

~~Socket~~
G
Bolt
Driving Cap
Driving Clamp

Fig: 134 DRIVING CLAMPS & CAPS.

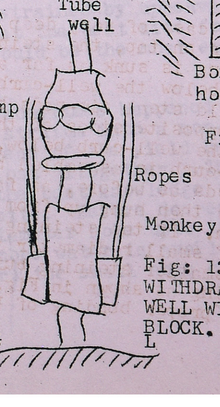

Tube well
Clamp
Ropes
Monkey
G
L

Fig: 135 WITHDRAWAL OF TUBE WELL WITH PULLEY BLOCK.

10, By the method of underpinning, ~~as in the~~ case of timber lining described in para 4 above.

11. A large supply of water is sometimes found by carrying the curb to a moderate depth below the spring level, and boring at 15 cm (6") diameter hole to a greater depth; if an iron pipe is passed down and left in the hole projecting a metre (3 or 4') above the bottom of the well to prevent its getting choked, success is sometimes attained, Fig.61.

12. Other forms steining:-- Corrugated iron lining Galvanised corrugated iron sheets are placed behind the settings of the timber steining instead of wall boards, and secured by bolts and nuts. This will make a better and more permanent steining than timber boards, and is less objectionable.

Earthenware rings:-- Wells lined with these are sometimes called pot wells. The steining consists of a number of earthenware rings, prepared and burnt by the village potter; they are generally 1 m (3') in diameter and 40 to 60 cm (15 to 24') high, and 5 to 10 (2 to 4") thick, Fig.133. The upper edge of each ring has a rim about 25 mm (2 1") high similar to that of an ordinary earthen ware drainage pipe.

One of these rings is placed on the sandy ground, and the sand inside is dug out, causing it to sink by pressure from above and regulating the excavation of sand beneath. When top of the ring is nearly level with the ground surface, a second ring is added on, being kept in position by the rim of the first ring. The excavation of sand is then continued as before, adding more and more rings as needed.

50. Deep Well

1. Selection of site for a deep well is a specialized art, requiring a thorough knowledge of the geology of the strata in the locality. The difficulties that present themselves in practice are (a) to know whether strata at the proposed site are on a synclinal or anticlinal axis, and (b) to know whether any impervious bank of clay underlines the permeable stratum or not.

2. As regards (a) observations may be made of sections of the earth's furface in nearby quarries, cuttings, river banks, etc. It will often be found that the strata do not necessarily follow the inclination of the ground surface. Synclinal axes may be found at tops of hills and anticlinal axes in valleys, due to the denudations of strata already strained by upheaval. Hence, it does not necessarily follow that the best site for a deep well is in a valley; however, it would be the most economical place to bore for water.

3. In deep wells, it has sometimes happened that deepening is carried through an impervious stratum into a non-water bearing porous one below, so that instead of the yield being increased, even the available supply is lost altogether. This danger must be guarded against by obtaining the best knowledge possible of the geological conditions at the site. Before deepening a well, it is better to bore a 10 cm (4") diameter hole upto the lower permeable stratum to find out wheather more water is available. In case there is any loss of available water, the small hole can be plugged and further loss prevented.

81. Tube wells.

1. The tube forming, the well are of iron and have an internal diameter of 32 mm (1¼") the external diameter being 43 mm (1 11/16") and are threaded at the ends for the length of 32 mm (1¼"). Each tube long, tapped to fit the tubes. The tube to be driven has a steel point welded to it, and a length of 50 cm (1'9") perforated with about 320 holes of 3 mm (1/8") diameter, and covered with a perforated brass sheathing to act as a strainer.

2. The well is driven into the ground by a series of blows delivered on either a steel Driving Cap or a steel Driving Clamp. (Fig. 134). A driving cap is a single block of steel with a hole through the centre. The lower part of the hole is threaded to fit on to the tube of the well, while the upper part is only 30 mm (1 3/16") in diameter, so that there is an internal shoulder which will rest on the top of the tube when the cap is screwed / fixed to any part of the tube by means of two bolts which squeeze them together; the inner surfaces of the clamp are serrated and hardened so as to grip the tube firmly.

/_ home. The driving clamp consists of two halves which may be

3. The blows are delivered by a cast iron monkey weighing about 40 kg. (84 pounds) having a 45 mm (1¾") diameter hole through the centre so as to slide freely upon the tube; two cotton ropes about 3 mm (9") long are fixed to the monkey and passed over a pulley block of two sheaves.

4. Driving the well:-- First a hole is made in the ground with a crow-bar to a depth of about two feet and the well tube inserted. The driving clamp is then screwed firmly on to the tube about 1 metre (3') from the ground, Fig.128, each bolt being tightened equally as not to indent the tube. In soft ground, the driving cap may be used straightway. The monkey is then placed up on the clamp or cap and the pulley bar inserted in the tube. The ropes are tied to the monkey and passed over the sheaves. The monkey is raised by two men pulling the ropes at the same angle; they should stand exactly opposite each other and work together and steadily, so as to keep the tube perfectly vertical and prevent it swaying about while being driven; if necessary, guy ropes may be fastened to the pulley bar to keep it vertical When the men have raised the monkey they lift their hands suddenly, thus allowing the monkey to fall with its full weight on to the clamp or cap. The bolts of the clamp must be tightened frequently to prevent it from sliding on the tube.

When the clamp is driven down to the ground, the monkey is raised off it, the clamp shifted 1 metre (2 or 3') above ground, and the driving is resumed as before. When a whole length of the tube is driven to the ground level, the monkey and the pulley bar are removed, and a fresh length of tube is screwed by means of a socket, on to the tube in the ground. (The two tubes must butt against one another perfectly, otherwise the screw-thread will be injured when driving is resumed). A little red lead should be placed on the threads of the socket before screwing up, to make the joint air-tight.

Before screwing on new lengths of tube, the well should be sounded by means of a small plumb line inserted down the tube. This will show the depth of water, if any, and also the nature of the soil which has penetrated through the holes at the bottom of the well.

5. Withdrawing of the pipes:- A tube well, when no longer required, may be withdrawn by one of the following methods:-

(a) In very soft ground, the tube may be withdrawn by wimply turning it round with a pair of tongs, right handed so as not to unscrew the joints, and lifted it up at the same time.

(b) In former ground, a short rope or chain is would round the tube close to the ground, and a lever may be used to ppll up the pipe slowly.

(c) The monkey is placed on the tube with its lower edge upwards, and the driving clamp screwed on face downwards about 30 cm (1') above it, Fig.135. The monkey is then raised sharply, and by striking the clamp, gradually the tube starts coming out.

6. The Tube-well pumps:- The water is raised by means of a special pump provided with the set. This pump is screwed on to the top and it is essential to make the top joint absolutely air-tight. Before starting the pump, it should be printed by pouring water into the top of the pump.

While sinking in certain kinds of soil, the bottom of the tube often gets choked, and a special set of cleaning tubes supplied with the set may be used to clear the tube.

If the well is to remain out of use for some time, the pump should be removed, and the top of the tube should be covered by an iron cap.

SECTION 16. CALCULATION OF YIELD

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82. Springs

1. In the case of a small spring, a tube may be inserted into the source, and the water issuing is collected for a definite time, say 30 minutes or 1 hour at a time and measured. This experiment is carried out in summer on a number of dry days and at different times of the day, to find out the minimum rate of flow and an average struck.

83. Streams and Rivers

1. The area A of cross-section of the stream up to low water level in the hottest season is calculated by measuring the depths of the water at different distances across the section. Then the surface velocity V of the water is found by noting the time taken by a floating body to travel a given distance, say 50 metres (yards). The amount of water Q amailable can then be calculated from the formula.

$Q = .8\ VA\ m^3$ (cft.) per sec.

where V = surface velocity in m per sec. (ft. per sec.)
and A = Area of cross section of stream at low water level in m^2 (sl. ft.)

Or $Q = .8VA\ (m^3)$ kl per sec. (cft. per sec.)

= 48 VA kilolitres per min. (300 gal/min.)

84. Wells

1. There are two ways of testing the yield of a given well, the Pumping test and the Recouperation test.

2. In the Pumping test, the water level in the well is depressed below the normal to a safe maximum working head and the yield at this depressed level is measured by the quantity of water that can be bailed out or pumped out in a given time so as to maintain this water level constant.

3. In the Recouperation test, the water surface in the well is depressed to any desired level below the normal and from this level it is allowed to refill to its normal level, the time taken to refill being carefully noted and the volume of water thus refilled worked out accurately. Here the observations should be not for volume of water in uniform periods of time, but for time required to refil uniform rises of level, say 10 cm (4") of height, till the normal surface is restored. Because, the rate of refilling is greater for greater head of depression and is slower as the water level is reaching its normal level.

The amount of water that can be supplied from the well can be calculated, from the simple formula

$$Q = \frac{.8\ hd^2}{t}\ \text{kl or } \left(\frac{5hd^2}{t}\ \text{gals. per min.}\right)$$

where Q = Yield in kilolitres (gals.) per minute,

h = height of water re-filled in metres (feet),
d = diameter of well in metres (feet).

and t = time taken in minutes to re-fill to a height of h metres (feet).

4. Spacing of wells in Sand and Alluvium:- When there are a number of wells in the vicinity, or when the supply is to be drawn from more than one well, observations should be made to determine the Cone of Depression by taking test holes at known distances from the test well, and finding out the area beyond which the normal water-table is left unaffected, while the test well is being drawn upon under various heads of depression, Fig.136 shows a typical Cane of Depression for a well. The spacing in fine sand should generally be about 60 m (200'), the exact distance being decided upon from observations.

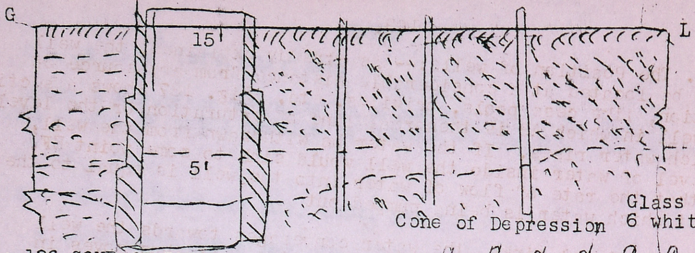
G
15'
5'
Cone of Depression
L

Fig: 136 CONE OF DEPRESSI ON

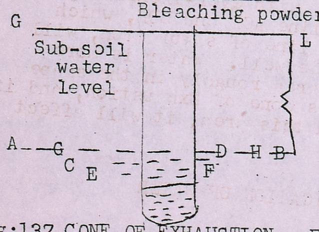
Bleaching powder
G
L
Sub-soil water level
A
G
C
E
D
H
B
F

Fig:137 CONE OF EXHAUSTION

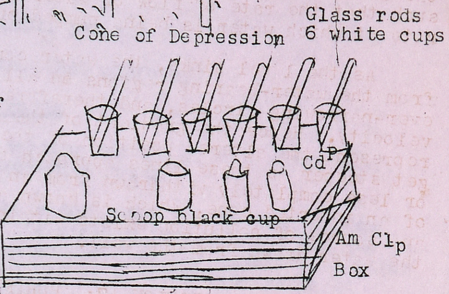
Glass rods
6 white cups
Cd^P
Scoop black cup
Am Cl$_p$
Box

Fig: HORROCK'S TEST BOX

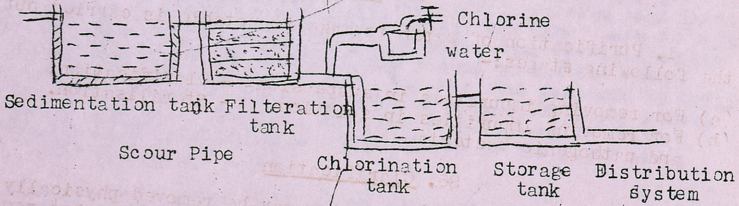
Chlorine water
Sedimentation tank
Filteration tank
Scour Pipe
Chlorination tank
Storage tank
Distribution system

Fig.139 PURIFICATION OF WATER

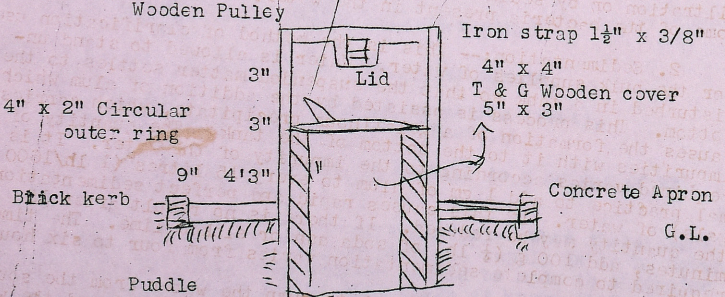
Wooden Pulley
Iron strap 1½" x 3/8"
3"
Lid
4" x 4"
T & G Wooden cover
5" x 3"
4" x 2" Circular outer ring
3"
9"
4'3"
Brick kerb
Concrete Apron
G.L.
Puddle filling
4" x ½" Iron ring
Steining
1" Tie-rod
The well-curb

Fig: 140 PROTECTION OF DRINKING WATER WELLS

5. The Position of wells:-- As already explained, the well should be located at a considerable distance from any source of pollution, like cess pools, priviles, etc. Fig. 137 shows a section of a well in which AB is thenormal line of saturation or the level to which water rises. If the water be withdrawn from the well, the level of water inside the well would sink to some point EF, such that the rate of flow of water into the well is equal to the rate at which water is being pumped out.

As the level sinks, the water converages towards the well from the water-bearing regions on all sides. It thus moves in ever-narrowing circles, and therefore, with ever-increasing velocity. Hence the gradient of the line ACF and BDF, which represent the altered position of the line of saturation, will get steeper as these lines approach the well. Water is more or less completely withdrawn from an area roughly in the shape of an inverted cone, which is known as Cone of Exhaustion, and if any source of pollution exists within this area, it will affect the water drawn from the well.

SECTION 17: PURIFICATION OF WATER

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85. General

1. Purification of water to make it potable is carried out in the following stages:-

(a) For removing impurities in suspension - Clarification.
(b) For removing impurities in solution - Sterilisation.
and pathogenic bacteria

86. Clarification

1. Suspended imprutiies in water may be removed physically by filtration or by sedimentation using alum. This will also remove some of the bacteria present in the water.

2. Sedimentation:-- This is the method of clarification used for the bulk supplies of water. Water is allowed to stand undisturbed in a tabk so that the suspended matter settles to the bottom. This process is assisted by the addition of alum which causes the formation of a gelatinous precipitate, which carries impurities with it to the bottom of the tank. The quantity of alum required varies according to the impurity of the [illegible]ter. It is normal practice to add 1 gm of alum to every 15 litres (1 lb/1600 gals) of water. If this causes rapid and perfect sedimentation the quantity may be reduced. If there is no result after 15 minutes, add 100 g (¼ lb) of soda ash or slaked lime. The time required to complete sedimentation varies from four to six hours.

3. In thefield it is usual to pump the water from the source into a tank. Alum is allowed to drip into the inlet and the water then remains still for the period of sedimentation before being drawn out. If a continuous supply is required, it is necessary to have two or more sedimentation tanks. The outlet of a sedimentation tank should be a few cm (inches) above the bottom, in order to be clear of sludge. The sludge requires periodical removal. To facilitate this, a scour pipe should be provided and the bottom of the tank should be sloped towards it, see Fig.139.

4. Filtration:-- The water from the sedimentation tank is then drawn into another tank filled with layers of clean gravel, and clean sand (course and fine) with an outlet at the bottom of tank. The water thus filtered through the material is then passed on to the Chlorination tank for sterilisation.

87. Sterilisation

1. Sterilisation destroys all the harmful bacteria present in the water. It may be carried out by various methods, depending upon availability of chemicals and also on the quantity of water which has to be treated.

2. Boiling:- This is only for individuals requirements. Boiling water for 5 full minutes mak s it quite safe for drinking.

3. Chlorination is the process of killing bacteria by the ~~use of~~ Chlorine gas. The cholorine may be used direct from the gas cylinders or it may be liberated by adding water to bleaching powder, etc.

Horrock's Test may be used for determining how much belaching powder must be added to any particular supply of water to destroy all harmful bacteria. The test box contains 6 white enamelled cups, one black enamelled cup, six glass rods, one glass tube or pipette, one measuring scoop, bleaching powder, Cadmium iodide solution, and amonium chloride tablets, Fig.138.

(a) Throughout the test use only water which has already been clarified.

(b) Put into the black enamelled cup one level scoopful of dry bleaching powder and make it into a smoother paste with a little water. Continue stiring and add more water until it reaches the mark on the inside of the cup.

(c) Place the white cups in a row and fill each cup to within 5 mm ($\frac{1}{4}$") of the brim with water to be tested.

(d) By means of a pipette held vertically, add to each of the cups 1,2,3,4,5 and 6 drops, respectively, of the solution from the black cup. Mix thoroughly with a clean glass rod.

(e) Allow them to stand for half an hour.

(f) To each white cup add three drops of the cadmium iodide (s-tarch) solution by means of the dropping bottle. Stir the contents of each with a clean glass rod.

(g) Water in some cups will show no change, but in others the liquid will turn blue. Note the cup with the smallest number of drops which has turned blue. The number of drops of the bleaching powder solution in this cup indicates the number of scoopfuls of bleaching powder required per 500 litres (110 gal. of the water. It will also indicate the number of parts of available chlorine per million parts of water required to render the water safe, provided that the bleaching powder is up to full strength, Thus, if the 4th white cup retains sky blue colour, 4 scoops of bleaching powder will be required to sterilise 500 litres (110 gal.) of water.

(h) If six drops of bleaching powder solution are not suffi-

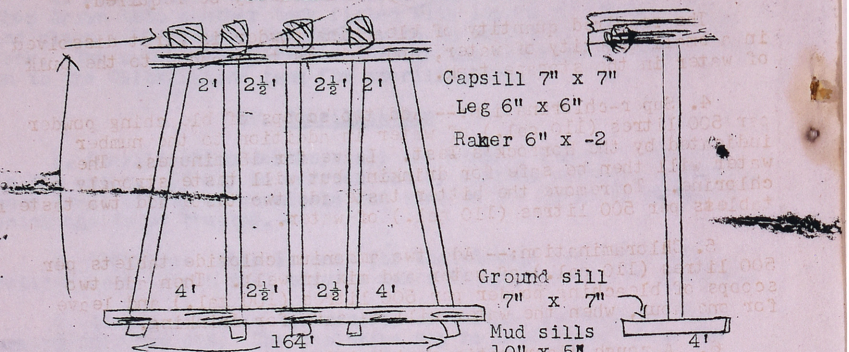
405 Tons
Road Bearers 12" x 12
2'
2½'
2½'
2'
Capsill 7" x 7"
Leg 6" x 6"
Raker 6" x -2
Ground sill
7" x 7"
4'
2½'
2½'
4'
164'
Mud sills
10" x 5"
4'

Fig:141 DESIGN OF A SINGLE TRESTLE PIER

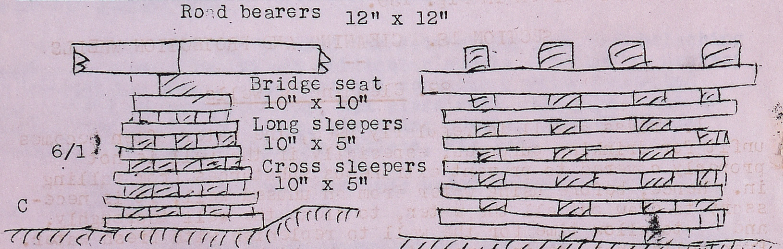
Road bearers
12" x 12"
Bridge seat
10" x 10"
Long sleepers
10" x 5"
Cross sleepers
10" x 5"
6/1
C

Fig: 142 DESIGN OF A CRIB PIER

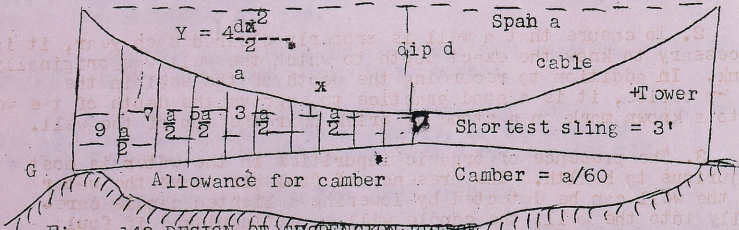
Y = 4dx²/a²
Span a
dip d
cable
a
x
Tower
9a/2
7a/2
5a/2
3a/2
a/2
Shortest sling = 3'
G
Allowance for camber
Camber = a/60

Fig : 143 DESIGN OF SUSPENSION BRIDGE
VERTICAL LENGTHS OF SUSPENDERS

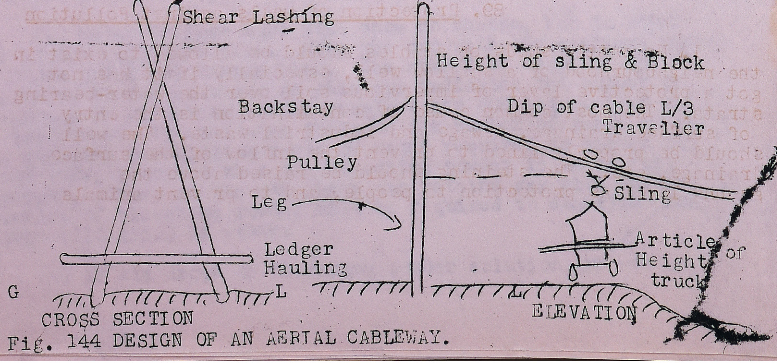
Shear Lashing
Height of sling & Block
Backstay
Dip of cable L/3
Traveller
Pulley
Sling
Leg
Article of
Height of
truck
Ledger
Hauling
G
L
L
CROSS SECTION
ELEVATION

Fig. 144 DESIGN OF AN AERIAL CABLEWAY.

cient to turn the water blue, the test must be repeated with 7 to 12 drops. This second test would rarely be required.

The required quantity of bleaching powder is first dissolved in a small quantity of water, and this is then added to the bulk of water in the storage tank.

4. Super-chlorination:-- Add two scoops of bleaching powder per 500 litres (110 gal.) of water in addition to the number indicated by the Horrock's Test. Leave for 15 minutes. The water will then be safe for drinking but will teste strongly of chlorine. To remove the bitter taste add two taste add two taste remove tablets per 500 litres (110 gal.) of water.

5. Chloramination:-- Add two ammonium chloride tablets per 500 litres (110 gal.) of water and mix in well. Then add two scoops of bleaching powder per 500 litres (100 gal.) and leave for one hour, when the water will be safe for drinking.

6. A rough diagramatic sketch indicating the process of water purification is given in Fig. 139.

SECTION 18. CLEANING AND PROTECTION WHELLS

88. Cleaning of wells

1. Unless a well is regularly used, the water often becomes unfit for drinking purposes, especially if the well is not properly covered to prevent extraneous substances from falling in. Hence, before using water from an unused well, it is necessary to draw out all the water, to clean the well thoroughly, and to allow time for the well to replenish with fresh water. Even wells that are in constant use should be cleaned from time to time to prevent accumulation of unwholesome matter in the water.

2. To ensure that a well is properly cleaned each year, it is necessary to know the exact depth to which the well was originally sunk. In addition to recording the depth of the well in the [illegible] office, it is a good practice to engrave the depth of the well upto a known mark on a stone or brick near the top of the well.

3. The presence of organic impurities in the water is most injurious to health. The presence of foul air above the water in the well can be detected by lowering a lighted candle carefully into the well; the candle will be extinguished if foul air is present. The cleaning of a well is generally carried out in seasons when the water supply runs, low.

89. Protection of wells against Pollution

1. No cattle sheds or stables should be allowdd to exist in the neighbourhood of a shallow well, especially if it has not got a protective layer of impervious soil over the water-bearing strata. The most common cause of contamination is the entry of surface drainage, sewage and industrial waste. The well should be properly lined to prevent the inflow of the surface drainage, etc. The steining should be raised above the ground level as protection to people, and to prevent animals

from falling in. Wells without the parapet walls should not be allowed to exist, as they are very dangerous.

2. A masonry or concrete platform may be provided round the well proper, sloping away from the well, to prevent any water, lifted out of the well and used for washing, etc., from flowing back into the well, Fig. 140. In community wells, a covering should be provided over the well to prevent leaves and other foreign matter from falling into it. The cheapest form of covering would be a light open shed roofed with tiles or corrugated galvanished iron sheets. Alternatively, a wood covering may be provided at the top of the steining with an opening under the pulley and a lid as shown in Fig. 140. No trees should be allowed to grow near a masonry lined well, since their roots are likely to force their way through the cracks in the masonry and break up the steining.

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